ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

Postgraduate Program

ESTIMATION OF SEDIMENT YIELD USING SWAT MODEL FOR KATAR WATERSHED

Thesis Submitted to the Addis Ababa Science and Technology University College of Architecture and Civil Engineering in Partial Fulfillment of the Requirement for the Degree of Masters of Science in Civil Engineering (Hydraulics Stream)

By

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JUNE, 2017

APPROVAL PAGE

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Abstract

The main objective of this study is to estimate the sediment yield to Lake Ziway from Katar catchment. In this study A physial, semi-distributed and continuous time, Soil and Water Assessment Tool (SWAT 2012) model having an interface with ArcView GIS software was used to estimate sediment yield and identify spatial distribution of sediment yield in the water shade. Sensitivity analysis, model calibration and validation were also performed to assess the model performance using (SWAT-CUP) on Katar River at Abura gauging station.. Fifteen sensitive parameters to stream flow were identified, of which runoff curve number (CN2) and Threshold depth of water in the shallow aquifer (REVAPMN) factor and similarly for sediment analysis six sensitive parameters were selected out of these channel re-entrainment linear parameter (SPCON), channel cover factor (CH_COV2), and channel erodibility factor (CH_COV1) was the most sensitive parameters affecting the hydrology of the catchment. The model was calibrated from 1992-2002 and validated from 2004-2008 G.C. Flow calibration gives coefficient of determination (R^2), Nash-Sutcliffe (ENS) and Percent bias (PBIAS), 0.8, 0.77 and -6.63 respectively and Validation gives R^2, ENS and PBIAS,0.78,0.75 and 5.3 respectively. Sediment calibration gives R^2, ENS and (PBIAS), 0.75, 0.73 and-10 respectively and validation test gives R^2, ENS and PBIAS, 0.65, 0.64, and 3.3 respectively. The stream flow and sediment yield of Katar Watershed was quantified and also the most sediment yielding part of the basin was identified. The model prediction result showed that the annual sediment yield leaving the watershed was found to be 2.1ton/ha/Yr.

Key Words: Ethiopia, Katar Watershed, SWAT Model, SWAT CUP, SUFI 2, Sedimentation, Simulation, Calibration, Validation

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Acknowledgment

First and above all, I praise God, the almighty for providing me this opportunity and granting me the capability to proceed successfully.

My Special thanks go to my supervisor Dr.Ing.Habtamu Itefa for his valuable advice, support, guidance, and above all for his close friendship all the way from the starting to the completion of the study. Furthermore, he has devoted his time and resources to advise me during the whole work to improve the thesis.

I am grateful to Ethiopian Road Authority that made this MSc possible through which I obtain the sponsorship during my study and also for Water Works Design and Supervision Enterprise staffs for their kindness to facilitate the entire necessary administrative procedure to carry out the study.

The kind collaboration of Ministry of Water, Irrigation and Electricity (Hydrology Data) and Ethiopian National Metrological Agency during my data collection process are very much appreciated.

My deepest gratitude goes to my friends, Shmeles meshesha, Dawit zerefa, Bereket Fikadu, and Helina Ayele, Who directly or indirectly contributed for the success of thesis work.

Finally, I would also like to thank my mother Shewanesh Gessese, and to my father G/silassie Dimtsu for the unconditional love and support they provided me throughout my life.

Last but most importantly, I would like to forward the largest thanks to my fiancé for helping and encouraging me through difficult times.

ACRONYMs

ACRU	Agricultural Catchment Research Units
AGNPS	Agriculture Non-Point Source Pollution Model.
ANSWERS	Areal Non-Point Source Watershed Environmental Response Simulation
ASTER	Advanced Space borne Thermal Emission and Reflection
EMA	Ethiopian Mapping Agency
EUROSEM	European Soil Erosion Model
GIS	Geographical information system
HSPF	Hydrologic Simulation Program Fortran
HRU	Hydrologic Response Unit
MoWIE	Minster of Water, Irrigation and Electricity.
MUSLE	Modified Universal Soil Loss Equation
NRCS	Natural Resource Conservation Service
RUSLE	Revised Universal Soil Loss Equation
SLEMSA	Soil Loss Equation Model for South Africa
SPAW	Soil-plant-Atmosphere-Water field and pond hydrology
SUFI 2	Sequential Uncertainty Fitting Version Two
SWAT	Soil and water Assessment Tool
SWAT CUP	Soil and water Assessment Tool Calibration and Uncertainty Procedures
T/HA/YR	Tons Per Hectare Per Year
USLE	Universal Soil Loss Equation
WWDSE	Water Works Design and Supervision Enterprise

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Inappropriate use of land for agriculture and poor management of its ecosystem lead to environmental problems such as land degradation through soil erosion. Erosion is the process of wearing away rocks, geologic, and soil material via water, wind, or ice (e.g., glaciers). Sediment is a natural product of stream erosion and Sedimentation is the process in which particulate matter carried from its point of origin by either natural or human-enhanced processes is deposited elsewhere on land surfaces or in water bodies. Soil erosion is a major watershed problem in many developing countries including Ethiopia causing significant loss of soil fertility, loss of productivity and environmental degradation. (Sujan D,2013).

Generally, soil erosion and ensuing sediment transport is a function of many processes. Predicting the amount of sediment coming into a reservoir, ponds or lakes, its deposition, and its accumulation throughout the years are important for hydraulic engineering.

General speaking problems, created by sediment erosion and deposition are many and varied. Excessive erosion can reduce the soil's inherent productivity, whereas the associated sedimentation can damage young plants and fill drainage ditches, lakes, and streams. Excessive sedimentation not only reduces the lake volume and depth but also influences water quality, aquatic habitat, navigation, recreation, real estate values, and tourism.

Sediment loading can have substantial negative effects not only on tourism and local economies (e.g. Clarke et al., 1985; Robertson & Colletti, 1994), but, more importantly, on people that rely on them for food. Thus it can be said that sedimentation poses a very serious problem to lake since it negatively impacts all of the beneficial uses of the lake.

Ethiopia covers a land area of 1.13 million km^2, of which 99.3 percent is a land area and the remaining 0.7 percent is covered with water bodies of lakes (MOWR, 2002). Because of an extremely varied topography, unevenness of the surface, a highland complex of mountains and bisected plateau characterizes the landscape; the rates of soil erosion and land degradation in the country are high, in addition to, the poor land use practices, improper management systems and lack of appropriate soil conservation measures. Which resulted in severe soil erosion and sedimentation, this in turn has been a serious threat to aquatic ecosystem.

The country soil depth of more than 34 % of the land area is already less than 35 cm (Zemenfes, 1995; SCRP, 1996). Hurni (1989) indicated that Ethiopia loses about 1.3 billion metric tons of fertile soil every year and the degradation of land through soil erosion is increasing at a high rate. According to Kruger et al, (1996) 4% of the highlands are so seriously eroded that they will not be economically productive again in a predictable future. The Soil Conservation Research Project (SCRP, 1996*)* has estimated an annual soil loss of about 1.5 billion tons from the highland. According to the Ethiopian Highlands Reclamation Study (EHRS, 1984) soil erosion is estimated to cost the country 1.9 billion US$ between 1985 and 2010. These call for immediate measures to save the physical quality of soil and water resources of the country.

The Central Ethiopian Rift valley is characterized by a chain of lakes and wetlands with unique hydrological and ecological characteristics. Increasing population pressure and economic developments put an increasing claim on the precious fresh water resources. Until recently, water from the lakes mainly supported agriculture and commercial fishery, domestic use, industrial soda extraction and recreation, while the lakes and surrounding wetlands supported a wide variety of endemic birds and wild animals. Recently, most researches indicate the cumulative effect of increase in population and climate change that enhance soil degradation and loss associated with erosion resulting from over exploitation of forests and vegetation covers. This human activity over the area has a great impact on the lake tributarries like rivers in the basin which increases rate of erosion and sediment. Meki and katar rivers,a tributarries for lake Ziway are good examples for the problem of sediment deposition in the lake.

SWAT model was used in this study to predict sediment load from the watershed discharged to the lake.Using the developed model, which attempted to quantify the impact of watershed intervention on the sediment budget helps or give an important input for water resource management of the area to provide sustainable and equitable supplies for communities in and around the catchment.

1.2. Statement of the Problem

The poor land use practices, improper management systems and lack of appropriate soil conservation measures have been major causes of soil erosion and land degradation problems in the country. One of the most environmentally vulnerable areas of the country is Central Rift Valley (CRV).

The Centeral Main Ethiopian Rift,characterized by many lakes and perennial rivers,is one of the most important places for water resources development, a few decades ago much of the basin was covered with natural vegetation. But, the fast growing population has induced land degradation and increases abstraction of water, this trend is still continuing (Halcorw,1989,Dagnachew legesse et al.,2003, Tenalem ayenew,2008). In addition,A serious existence of Land use change and rapid expansion of land degradation over the region is detected in the past 33 years (1973-2006), land degradation had been expanding by about 60km^2 every year and hence strongly affecting the livelihood of the society by mainly decreasing crop production (Derege Tsegaye et al.,2006). The four major lakes (Ziway, Langano, Abijata, and Shala) in the region also showed a serious of decline in size.Also the researchers suggest that a more detail study of the degradation amount in relation to soil erosion, sediment yield to the lakes and catchment characteristics should be made using adaptable models.

Besides the above two research,the study which is made by Damtew Fufa Tufa to evaluate land use and land cover changes between 1986 and 2010 years and its impact on katar watershed hydrology, the result of the analysis stated that mean monthly flow during wet season increase by 3.8%,while during dry season decreased by 12.3% in 2010 compared to 1986 due to LULC change. Similarly,the contribution of surface runoff also increased from 40.6% to 45% b/n the period of 1986 to 2010.From the study,it can be concluded that deforestation of natural forest and increased in farm land experenced by the rapid increase of population which can be a major cause for soil erosion in katar watershed. (Damtew F,2015).

Lake Ziway is a part of central rift valley lakes and the only freshwater lake in the area used for drinking water, small scale commercial fishing and irrigation purpose. Because of, a serious existence of Land use change and rapid expansion of land degradation over the region is showed, this will increase the chance of sedimentation in the lake. which may lead to, making the lake more shallow, reduce the amount of surface area, decrease the water volumes and lake storage capacity, reduce water clarity and decrease light penetration, increase water temperatures, smother fish eggs and bottom-dwelling life forms, stimulate nuisance algae blooms, provide additional rooting sites for waterweeds, promote fish kills, prevent recreational boating, swimming, and fishing, impair the natural scenic beauty, and depreciate property values etc. which has a big effect on the society, those there life span depend mainly on the lake.

The major sources of erosion on the watershed area are wind, ice, vegetation, precipitation and flow. However, for the modeling purpose, only precipitation and flow-initiated erosion is taken into account. Although, wind and ice might have impact on the erosion process, they have a relatively low contribution to the river sedimentation process.

Lake sediments can originate from within the lake itself or externally from the surrounding watershed. Estimation of the sediment yield from catchments is required for the studies of sedimentation in lakes.Meki and Katar rivers are the main rivers draining western and eastern part of the catchment respectively and both feed Lake Ziway before outflow to Bulbula River, which is the major tributary of the lake abiyata. The Shrinkage of water surface area of Lake Ziway's has further reduced the discharge of the Bulbula River into Lake Abiyata.

previous studies focus mainly on the rift lakes. however, the hydrological behavoir of the lakes is very much dependent on what happens in their catchment.Therefore, this research will focus on the prediction of sediment inflow to Lake Ziway by main tributariy catchment of Katar. The finding of this research will help to guide the implementation of Watershed development and management by giving more attention to erosion prone areas and also help by providing necessary information for more execution of different works to prevent Lake Ziway from dry up.

1.3. Objective

General Objective

The general objective of the research is to estimate the sediment yield to lake Ziway from the inflowing major tributary of Katar River.

Specific Objective

To fulfill the above general objective the following specific objectives are used.

- ❖ To estimate the total annual sediment yield supply to Lake Ziway from Katar Watershed.
- ❖ To assess and evaluate the spatial variability of sediment yield in the watershed
- ❖ To identify the most problematic sub basin with respect to sedimentation

1.4. Research question

1. How much quantity of sediment will be transported to the lake Ziway by Katar River?
2. What look like the spatial variability of sediment yield?
3. Which area is the most erodiable in the watershed ?
4. What is the gap between the simulated and observed result shows?

1.5. Thesis Outline

This thesis encompasses eight chapters.

- Chapter one gives a general introduction to the study with its back ground of the problem, objectives of the research study and layout of the thesis.
- Chapter two covers literatures on the concepts of impact of land use on water resource development and sedimentation problem for land use impact through application of models for the prediction of sediments. Hydrologic modeling, experiences of using SWAT model for sediment assessment and previous works in the study area is also reviewed in this chapter.
- Chapter three covers a brief description of the study area including its location and deals with the methodology adopted for the study, data analysis, model calibration and validation and model evaluation are presented,
- While in chapter four the model results, calibration and validations are discussed.
- Finally, Chapter five leads to conclusion and recommendation.

CHAPTER TWO

2. LITRATURE REVIEW

2.1. Previous work in the study area

The central Ethiopia rift valley includes the study area has been the interest of many researchers and organizations, though they are not recent, in recognition of the severity of erosion and their consequences.

Among many researches made in study area, focusing on hydrology, water resource potential assessment, land use, climate and hydrogeology which directly or indirectly related to the current study Will be reviewed as follows: -

HALCROW (2008), in the work entitled 'Rift Valley Lakes Basin Integrated Resources Development Master Plan'. These study conduct different analysis includes hydrological analysis, evaluation of the hydrometerlogical network, bathymetric survey, sediment analysis, flood risk management and impact of climate change.

The main objective of the study is to prepare a Master Plan which contributes to the sustainable development and poverty reduction of the Rift Valley Lake Basin which, makes optimum use of all resources of the basin on an integrated basis, has the minimum adverse environmental impact and socially and politically acceptable.

In the study, two regional suspended sediment equations have been established. Two sub-basins have been identified: North – Ziway-Langano-Abiyata-Shala, and South – Awassa-Abaya-Chamo. These two sub-basins have each been further divided into western and eastern catchments as distinctly divided by the rift system. Annual sediment yield entering to lake ziway from the Katar watershed calculated by the study is 128 ton/km^2/year.

The study identify the important Development Interventions are

- Improvement of the hydrometric data processing and management capacity
- The upgrading of the hydro meteorological network and data collection operations
- Improvement of the hydro meteorological data processing and management capacity

ADDISU D (2005), 'Evaluation of land degradation and soil erosion hazard assessment using GIS and USLE model in Katar catchment'. The main objective of the study is to assess spatial soil erosion hazard and land degradation based on GIS Model, Universal soil loss equation (USLE). Field measurements were taken in the study to generate the C and P factors and also for gully erosion.

The result of the study grouped the study area in to 6 erosion classes of < 4.71, 4.71-9.42, 9.42-28.56, 28.56- 51.83,51.83-98.94 and > 98.94 t/ha/yr. but in general the resulting showed that 96.81% of the area has a soil erosion rate of less than 9.42 t/ha/yr, which is less than the rate of soil formation

ALEMU D (2006), 'groundwater–surface water interaction and analysis of recent changes in hydrologic environment of lake Ziway catchment', Groundwater and surface water interaction in the area have been analyzed using groundwater table contour, field base river discharge measurements, channel water balance and hydrographic analysis.

As a result of the thesis, the hydrograph of Katar River at Abura is smooth, showing less response to daily precipitation, higher runoff after immediate end of wet season but declining at faster rate. Furthermore, the five years moving average of the precipitation in the catchment shows that there is decrease in rainfall by about 30mm every five years.

and trends in potential evapotranspiration indicate about 215mm rise on land surface from 1995 to 2004 and 260mm on Lake Surface from 1979 to 2004.

Along with, in annual basis, groundwater outflow is greater than groundwater inflow. The recession in groundwater inflow over outflow is higher in the months of July and August due to time lag between commencement of surface moisture and contribution of groundwater to the lake on one hand and the increase in groundwater outflow due to rising lake level on the other hand.

The research also indicates abstraction of water from rivers and directly from the lake for irrigation and municipal purposes is increasing and currently reached about 76mcm annually. Declines in base flow as well as ratio of adjusted dry season river discharge to the respective wet season of the same hydrologic year show the recession of groundwater recharge. Lake level and its outflow to Bulbula River are declining recently as a result of cumulative effect of both climatic and anthropogenic factors. The lake level has been declined by about 300mm from 1990 to 2005.

DAMTEW F (2015), ‘hydrological impacts due to land use and land –cover changes of Katar watershed, lake Ziway catchment, Ethiopia’, which asses the temporal effect of LULC changes on stream flow of Katar river and also evaluate the changes between 1986 and 2010 years using Semi-distributed hydrological model, Soil and Water Assessment Tool (SWAT).

The analysis result of the study show that, an outspread of agricultural land and settlement and reduction of forest land and grass land in the study area. Agricultural land was increased by 27.7% between 1986 and 2010, with annual rate of (15.5 km^2/year).while grassland, Natural forest, Afro-alpine vegetation and wet land decreased by 33.7 %, 53 %, 6.2 and 15% respectively.

Generally, the result of analysis indicated that changing of forest land and grassland to agricultural land and urban area has altered rainfall-runoff relationship and resulted in increased wet season surface flow and reduction of dry season water flow.

The researcher recommends, the land-use/land-cover change should be controlled in the watershed and some measures should be taken for the stabilization of the land cover change to sustain the contribution of groundwater in dry season and ecological bio-diversity within the basin.

JORDI PASCUAL,et,al. (2013), 'Assessment of water resources management in Ethiopian Central Rift Valley: environmental conservation and poverty reduction.' The journal assesses the relation between water management, environmental degradation and poverty through a stakeholder analysis focused on the status and management of water resources.

The study was conducted by prepare interviews with the different stakeholders (federal goverement,regional government,district goverement,municipal goveremnt,non-profit organization and private organization) and it is possible to draw the following findings regarding key water-related issues in the CRV basin:-

- The over exploitation of water resources currently hindering ecosystem survival and the result of growing competition for water among subsistence farming, industrial farming and tourism promotion
- Deteriorating water quality, which affects irrigated agricultural production and renders water unsuitable for drinking

- The great dependency of the population on water resources to sustain their livelihoods.

The study indicates the above mentioned issues can be addressed by strengthening water governance and should be improve water quality and reduced over drafting will also enhance environmental sustainability and contribute towards reducing poverty.

DEREGE T,et,al. (2006), ‘Continuing land degradation and its Cause-Effect in Ethiopia’s central rift valley’, the paper estimate the serious existence of LULC and rapid expansion of land degradation over the study area.

In the study the spatial analysis of the 1973, 1985 and 2006 classified image maps were used to show that various major changes had occurred in the region. Therefore, in each period, the land category with the largest proportion of Land use and cover was agricultural land, but degraded land increased rapidly between 1973 and 2006.

The researchers point out, As a result of the expansion of land degradation over time, agricultural production has found being decreased and worsened food insecurity (shortages) and poverty in the region. In addition, if current trends in LUCC continue, it is projected as Lake Abiyata might dry up by 2021. Finally, strong suggestion were made by the researchers that a more detail study of the degradation amount in relation to soil erosion, sediment yield to the lakes and catchment characteristics should be made using adaptable models; so as to guide the implementation of comprehensive and sustainable land use management by giving more attention to erosion prone areas.

WWDSE (2006), Ziway irrigation project feasibility study, the objective of the study is development of sustainable pressurized irrigation system using water from Lake Ziway to attain by reducing evaporation from lake without affecting the natural flow to Lake Abiyata.

HEC-5 program has been used to model the water resource system of the Ziway-Langano-Abiyata sub-basin. The 1969-2004 hydrological data are used for the planning period to assess the impact of Ziway Pressurized irrigation expansion plus 19 scenarios with 5000, 10000 and 15000ha on Lake Ziway-Langano-Abiyata sub-basin.

The study was conduct initial estimate on sediment entering into Lake Ziway and Langano. And the total sediment inflowing to lake Ziway is 1.6 million m^3, some reduction of sediment into these lakes may occur due to deposition on delta especially for Meki river.

In addition, the study estimates infield irrigation drainage parameters for the project area by considering time of concentration of runoff. For irrigation field the runoff allowed to stay not more than two hours and taking two hour rainfall of 5 years return period of magnitude as 39mm the resulting peak runoff for field slope (0-5%) is 2.7 $m^3/s/km^2$, for field slope (5-10%) is 3.7 $m^3/s/km^2$. Plus peak runoff result 5.2 $m^3/s/km^2$ taking the time of concentration for escarpment area small as one hour and one hour rainfall of 5 year return period of magnitude is 47mm.

In all studies conducted so far, there is limited consideration of the role of sedimentation which inflow from the surrounding catchment to the lake in affecting the hydrogeological dynamics of the lake under consideration. Moreover, the recent studies consider only the LULC change of the area even if, this change facilitates the sedimentation inflow to the lake. Monthly basis sediment calculation by the SWAT model after incorporating recent data to the existing ones are new work that provide useful information for Policy makers and general public to manage the resource on sustainable basis.

2.2 Erosion and Sedimentation

2.2.1 Factors affecting soil erosion

Soil erosion is a complex process that involves soil properties, topography (surface area, slope length, slope gradient), vegetation cover, rainfall intensity and land management systems (Nyssen et al., 2004; Pimentel, 2006); we can say those are the factors which influence soil erosion.

The basic energy input required to drive erosion processes is provided by rainfall and runoff. Therefore, rainfall is identified as the main cause of water erosion. Greater the intensity and duration of a rain storm, the higher the erosion potential. The impact of raindrops on the soil surface can breakdown soil aggregates and disperses the aggregate material. Lighter aggregate materials such as very fine sand, silt, clay and organic matter are easily removed by the rain drop splash and runoff water; greater raindrop energy or runoff amounts are required to move larger sand and gravel particles.

The edibility of soil also affects soil erosion.it is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Texture is the principal characteristics affecting erodibility, but structure, organic matter and permeability also contribute. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have great resistance to erosion. Sand, sandy loam and loam-textured soils tend to be less erodible than silt, very fine sand and certain clay-textured soils.

Soil erosion by water is also a function of steepness (gradient), slope length, and shape. The steeper and longer the slope of a field, the higher the risk for erosion. Soil erosion by water increases as the slop length increases due to the greater accumulation of runoff which permits a greater degree of scouring cause sediment transport. (Jim Ritter,2012).

Vegetation Cover and Management also have a direct link to soil erosion. The potential for soil erosion increases if the soil has no or very little vegetative cover of plants/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of runoff water and allows excess surface water to infiltrate. Crop management system that favors contour farming and strip-cropping techniques can further reduce the amount of erosion. To reduce most of the erosion on annual row-crop land, leave residue cover greater than 30% after harvest and over winter months, or inter-seed a cover crop (e.g., red clover in wheat, oats after silage corn); (Jim Ritter,2012).

2.2.2 Impact of land use on erosion and sediment load

Land degradation and erosion hazard induced by water erosion, human and physical factors, particularly the denudation of vegetation by human and domestic animals, and the infrequent and irregular distribution of precipitation are becoming a major problem worldwide. The effects are seen more in developing countries than in the developed countries because of the high population growth rate and the associated rapid depletion of natural resources (Feoli et al., 2000).

The unsustainable agricultural practices along with many other physical, socioeconomic and political factors have been the driving forces to a series of land degradation problems in the country. According to some studies, for instance El-Swaify and Hurni (1996) the highlands of Ethiopia are considered to be amongst the most degraded lands in Africa.

Deforestation may increase erosion. The actual soil loss, however, depends largely on the use to which the land is put after the trees have been cleared. Surface erosion from well-kept grassland, moderately grazed forests and soil-conserving agriculture are low to moderate (Bruijnzeel, 1990).

Effects of erosion control measures on sediment yield will be most readily felt on-site. There is an inverse relation between basin size and sediment delivery ratio. In basins of several hundred km2 improvements may only be noticeable after a considerable time lag (Decades), due to storage effects (Bruijnzeel, 1990). Downstream sediment yields cannot always be ascribed to the changing of upstream land use practices. Human impacts on sediment yield may be substantial in regions with stable geological conditions and low natural erosion rates. In regions with high rainfall rates, steep terrain, and high natural erosion rates, however, the impact of land use may be negligible.

Forests are checkers of soil erosion. Protection is largely because of under storey vegetation and litter, and the stabilizing effect of the root network. On steep slopes, the net stabilizing effect of trees is usually positive. Vegetation cover can prevent the occurrence of shallow landslides (Bruijnzeel, 1990). However, large landslides on steep terrain are not influenced appreciably by vegetation cover. These large slides may contribute the bulk of the sediment, as for example in the middle hills of the Himalayas (Bruijnzeel and Bremmer, 1989).

2.2.3 Overview of soil erosion and hydrological modeling

Many hydrological and soil erosion models are developed to describe the hydrology, erosion and Sedimentation processes. These models are generally meant to describe the physical processes controlling the transformation of precipitation to runoff and detachment and transport of Sediments (Fasil G, 2012).

Erosion modeling is based on understanding the physical laws of landscape processes that occur in the natural environment. Erosion models can provide a better understanding of natural phenomena such as transport and deposition of sediment by overland flow and allow for reasonable prediction and forecasting. Many different models have been proposed to describe and predict soil erosion by water and associated sediment yield. They vary considerably in their objectives, time and spatial scales involved *(Shimelis G, 2008).*

Watershed hydrology and river water quality models are important tools for watershed management for both applied and operational research purposes. For this purpose several available empirical, physically based or conceptual models could be used.

Empirical models are based on defining important factors through field observation, measurement, experiments and statistical methods *(Petter, 1992).* They are useful in predicting the hydrology or soil erosion, but are site specific and require long-term data *(Elirehema, 2001).* Among the commonly used empirical erosion models include: the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE) and the Soil Loss Estimation Model for South Africa (SLEMSA). *(Adissu D, 2005)*

Physically based models are based on knowledge of the fundamental processes and incorporate the laws of conservation of mass and energy *(Petter, 1992).* These physical processes vary both temporally and spatially. They consider the spatial and temporal changes of different factors *(Jaroslav et al., 2007).* Physically based distributed watershed models play a major role in analyzing the impact of land management practices on water, sediment, and agricultural chemical yields in large complex water-sheds. The Areal Non-Point Source water Shed Environment response simulation (ANSWERS), Water Erosion Prediction Project (WEPP), European Soil Erosion Model (EUROSEM) and soil and water assessment tool (SWAT).

Conceptual models are based on spatially lumped forms of water and sediment continuity equations. As explained by *Merritt et al. (2003)* these models are general description of catchment processes, without including the specific details of process interactions, which would require detail catchment information. Conceptual models play an intermediary role between empirical and physically based models. The main feature that distinguishes the conceptual models from the empirical models is that the conceptual models, whilst they tend to be aggregated, they still reflect the hypothesis about the processes governing the system behavior. The Agricultural Non-point Source Pollution Model (AGNPS), Agricultural Catchment Research Unit (ACRU), Hydrologic Simulation Program, Fortran (HSPF) are among the conceptual models used in erosion and/or water quality studies.

Hydrological models are also classified as either lumped, distributed and a semi distributed, which is a mix of based on the spatial discretization or resolution. Lumped models assume homogeneous or average conditions over all or portions of a watershed and are not sensitive to actual locations of the varying features in the watershed. Distributed models are taking into account the location of various watershed conditions such as land covers, soil types and topography to estimate the total runoff, however, the model require more detailed data. Some models are mixes of the two types of models, in other words, quasi or semi distributed models made up of multiple connected lumped models representing different parts of watershed. These models attempt to calculate flow contributions from separate areas or sub-basins that are treated as homogeneous within themselves. (Wheater,H., et, al. 2008)

A good model should satisfy the requirements of reliability, universal applicability, ease of use with a minimum data, comprehensiveness in terms of the factors and erosion processes included and the ability to take account of changes in land use and conservation practice (Morgan, 1995). The main criteria that were considered for selection of soil erosion models used in most studies are less input requirement, computational simplicity, wide applicability and relative validity in the study area.

2.3 Hydrological modeling

2.3.1 Definition of modeling

A model in its broadcast sense is a simplified depiction of a natural entity that in some way exhibits its important features while eliminating or suppressing matters of irrelevant detail. In science and engineering, an essential attribute of a model is that it be quantitative, specifically, that it yields a numerical value for a feature of the natural entity, as a replacement for a measurement. A quantitative model can be used to explore cause and effect relations and to determine values of physical variables that are too costly or difficult to measure directly. Models have long been used in water resources management to guide decision making and improve understanding of the system. It is essential that a model used in water resources management be sufficiently accurate for its intended purpose. Because a model is a simplified depiction of the natural system, its accuracy is subject to question until proven the acceptability of a model can only be determined by a confrontation with observation. Therefore, the existence of a model does not avoid the need for data from the watercourse, but in fact imposes additional needs and requirements on the data base. (Fasil G, 2012)

There are various criteria which can be used for choosing the right hydrological model for a specific problem. These criteria are always research dependent, since every project has its own specific requirements and needs. Further, some criteria are also user-dependant (and therefore subjective). Among the various researches - dependent selection criteria, there are four common, fundamental ones that must be always answered (Cunderlik, 2003):

- Required model outputs important to the research and therefore to be estimated by the model (Does the model predict the variables required by the research such as long-term sequence of flow?)
- Hydrologic processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating single-event or continuous processes?)
- Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the research?)
- Price (Does the investments appear to be worthwhile for the objectives of the research?)

2.3.2 Theoretical description of SWAT

The SWAT model is a long-term, continuous simulation watershed model. It operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields. The model is physically based, computationally efficient, and capable of simulating a high level of spatial detail by allowing the division of watersheds into smaller sub watersheds *(Neitsch et al, 2005).* SWAT models water flow, sediment transport, crop/vegetation growth, and nutrient cycling.

The model allows users to model watersheds with less monitoring data and to assess predictive scenarios using alternative input data such as climate, land-use practices, and land cover on water movement, nutrient cycling, water quality, and other outputs. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. Several model components have been previously validated for a variety of watersheds.

In SWAT, a watershed is divided into multiple sub watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. Climatic inputs used in SWAT include daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data, which can be input from measured records and/or generated and also the model uses the data from the station nearest to the centric of each sub basin.

Flows are summed from all HRUs to the sub watershed level, and then routed through the stream system using either the variable storage method or the Muskingum method. Surface runoff from daily rainfall is estimated using a modified SCS curve number method, which estimates the amount of runoff based on local land use, soil type, and antecedent moisture condition. Peak runoff predictions are based on a modification of the Rational Formula *(Chow et al, 1988).* The watershed concentration time is estimated using Manning’s formula, considering both overland and channel flow.

The soil profile is subdivided into multiple layers that support soil water processes including infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. The soil percolation component of SWAT uses a water storage capacity technique to predict flow through each soil layer in the root zone

The model computes evaporation from soils and plants separately. Potential evapotranspiration can be modeled with the Penman-Monteith *(Monteitch, 1965),* Priestly-Taylor or Hargreves methods, depending on data availability.

Sediment yield in SWAT is estimated with the modified soil loss equation (MUSLE) developed by *(Wischmeier & Smith, 1978).* The sediment routing model consists of two components operating simultaneously: deposition and degradation. The deposition in the channel and flood plain from the sub-watershed to the watershed outlet is based on the sediment particle settling velocity. The settling velocity is determined using Stokes law *(Chow et al, 1988)* and is calculated as a function of particle diameter squared. The depth of fall through a reach is the product of settling velocity and the reach travel time. The delivery ratio is estimated for each particle size as a linear function of fall velocity, travel time, and flow depth. Degradation in the channel is based on Bagnold‟s stream power concept *(Bagnold, 1977).*

2.3.3 Hydrological Component of SWAT

Simulation of hydrology of a watershed is done in two separate components. One is the land phase of the hydrologic cycle that controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that will be loaded into the main stream.

Hydrological components simulated in land phase of the Hydrological cycle are canopy storage, infiltration, redistribution, and evapotranspiration, lateral subsurface flow, surface runoff, ponds and tributary channels return flow. The second component is routing phase of the hydrological cycle in which the water is routed in the channels network of the watershed, carrying the sediment, nutrients and pesticides to the outlet. In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation.

$$\mathbf{SW_{st} = Sw_o + \sum_{i=1}^{\infty} (R_{day} - Q_{suf} - E_a - W_{seep} - Q_{gw}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1}$$

Where: SWst is final soil water content (mm H2O), SWo is initial soil water content on day I (mm),t is time (days), Rday is the amount of precipitation on day i (mm H2O) ,Qsurf is amount of surface runoff on day i (mm H2O) ,Wseep is amount of water entering vadose zone from the soil profile on day I (mm H2O), Ea amount of evapotranspiration on day I (mm H2O) ,Qgw amount of return flow in day I (mm H2O).(Neitsch S.et,al 2011)

Surface Runoff

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. Using daily or sub daily rainfall, SWAT offers two methods for estimating surface runoff: the SCS curve number procedure (USDA-SCS, 1972) and the Green & Ampt infiltration method (Green and Ampt, 1911).

Even though the latter method is better in estimating runoff volume accurately, its sub daily time step data requirement makes it difficult to be used for this study. SWAT simulates surface runoff volumes and peak runoff rates for each HRU. The SCS curve number equation is *(SCS, 1972):*

$$\boldsymbol{Qsurf} = ((R_{day}-I_a)^2)/(R-I_a+S))\ldots\ldots\ldots\ldots..2.2$$

In which, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), Ia an initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm water), S is the retention parameter (mm). The retention parameter is defined by equation 2.3,

$$\boldsymbol{S = 25.4} * \left(\frac{\boldsymbol{1000}}{\boldsymbol{CN}} - \boldsymbol{10}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.2.3$$

Where CN is the curve number for the day and it is a function of land use, soil permeability and antecedent soil water condition. Commonly Ia is approximated by 0.2S and equation 2.3 can be rewrite as follow

$$\boldsymbol{Qsurf} = (\boldsymbol{Rday - 0.2s})\boldsymbol{2}/(\boldsymbol{R + 0.8s})\ldots\ldots\ldots\ldots\ldots\ldots\ldots.2.4$$

For the definition of hydrological groups, the model uses the U.S. Natural Resource Conservation Service (NRCS) classification. The classification defines a hydrological group as a group of soils having similar runoff potential under similar storm and land cover conditions. Thus, soils are classified into four hydrologic groups (A, B, C, and D) based on infiltration which represent high, moderate, slow, and very slow infiltration rates, respectively. (Neitsch S.et,al 2011)

Peak runoff rate

The peak runoff rate is an indication of the erosive power of a storm and is used to predict sediment loss. SWAT calculates the peak runoff rate with modified rational method for each HRU as follows:

$$\mathbf{Q}_{\mathbf{peak}} = \frac{\mathbf{Q\ surf} * \boldsymbol{\sigma}_{\mathbf{tc}} * \mathbf{A}}{\mathbf{3.6} * \mathbf{t}_{\mathbf{conc}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{2.5}$$

Where Q_{peak} is a peak runoff rate (m^3/s), t_c the fraction of daily rainfall that occurs during the time of concentration, Q_{surf} is the surface runoff (mm), A is the sub-basin area (km^2), t_{conc} is time of concentration (hr) and 2.6 is conversion factor; to calculate the value of $\boldsymbol{\sigma}_{\mathbf{tc}}$ SWAT uses the follow equation,

$$\boldsymbol{\sigma}_{\mathbf{tc}} = \mathbf{1} - \mathbf{exp}(\mathbf{2} * \boldsymbol{tconc} * \mathbf{ln}(\boldsymbol{\alpha} + \boldsymbol{\beta}))\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{2.6}$$

Where $\boldsymbol{\sigma}_{0.5}$ is the fraction of daily rain falling in the half-hour highest intensity rainfall, tconc is the time of concentration for the sub basin (hr).

Potential evapotranspiration

Numerous methods have been developed to estimate PET. Three of these methods have been incorporated into SWAT; Penman-Monteith (Monteith, 1965), Priestley-Taylor and Hargreaves methods. These methods have various needs for a number and type of climate variables: Penman-Monteith method requires solar radiation, air temperature, relative humidity and wind speed; Priestley-Taylor method requires solar radiation, air temperature and relative humidity; whereas Hargreaves method requires air temperature only.

Brief description of some of the key model components which is important concepts for this study are provided as mentioned above. But, more detailed descriptions of the different model components are listed in *Arnold et al., (1998),* Neitsch *et al., (2005).*

Groundwater

The simulation of groundwater is partitioned into two aquifer systems i.e an unconfined aquifer (shallow) and a deep-confined aquifer in each sub basin. The unconfined aquifer contributes to flow in the main channel or reach of the sub basin. Water that enters the deep aquifer is assumed to contribute to stream flow outside the watershed *(Arnold et al., 1993).* In SWAT model the water balance for a shallow aquifer is calculated with equation 2.7.

$$aq_{sh,i}=aq_{sh,i-1}+wr_{chrg,sh}-Q_{gw}-w_{revap}-w_{pump,sh} \ldots\ldots\ldots\ldots 2.7$$

In which $aq_{sh,i}$ is the amount of water stored in the shallow aquifer on day i (mm), aqsh,i-1 is the amount of water stored in the shallow aquifer on day i-1 (mm), w_{rchrg} is the amount of recharge entering the aquifer on day i (mm), Qgw is the groundwater flow, or base flow, into the main channel on day i (mm), w_{revap} is the amount of water moving into the soil zone in response to water deficiencies on day i (mm), w_{deep} is the amount of water percolating from the shallow aquifer into the deep aquifer on day i (mm), and $w_{pump,sh}$ is the amount of water removed from the shal-low aquifer by pumping on day i (mm). The steady-state response of groundwater flow to recharge is estimated by equation 2.8 *(Hooghoudt, 1940).*

$$\mathbf{Q_{gw} = \frac{800 * K_{sat}}{L_{gw}^2} * h_{wtbl}} \ldots\ldots\ldots\ldots \mathbf{2.8}$$

In which K_{sat} is the hydraulic conductivity of the aquifer (mm/day), L_{gw} is the distance from the ridge or sub basin divide for the groundwater system to the main channel (m), and hwtbl is the water table height (m). Water table fluctuations due to non-steady-state response of groundwater flow to periodic recharge are calculated by equation 2.9 *(Smedema and Rycroft, 1983).*

$$\mathbf{dh_{wtbl}/dt=(W_{rchrg,sh}-Q_{gw})/800\times\mu \ldots\ldots 2.9}$$

In which, $\mathbf{dh_{Wtbl}/dt}$ is the change in water table height with time (mm/day), $W_{rchrg,sh}$ is the amount of recharge entering the aquifer on day i (mm) and μ is the specific yield of the shallow aquifer (m/m). Assuming that variation in groundwater flow is linearly related to the rate of change in water table height, equations 2.8and 2.9 can be combined to obtain equation 2.10

$$\mathbf{dQ_{gw}/dt=10(K_{sat}/\mu L_{gw}^{2})*(W_{rchrg,sh}-Q_{gw}) = \alpha_{gw}(W_{rchrgh}-Q_{gw}) \ldots\ldots 2.10}$$

In which α_{gw} is the base flow recession constant or constant of proportionality, The base flow recession constant, gwα, is a direct index of groundwater flow response to changes in recharge (Smedema and Ry-croft, 1983). $\boldsymbol{\alpha_{gw}}$ varies from 0.1-0.3 for land with slow response to recharge to 0.9-1.0 for land with a rapid response. Although the base flow recession constant may be calculated, the best estimates are obtained by analyzing measured stream flows during periods of no recharge in the watershed.

2.3.4 Sediment component of SWAT

Erosion and sediment yield caused by rainfall and runoff are estimated through SWAT for each sub-basin with the Modified Universal Soil Loss Equation (MUSLE).The modified universal soil loss equation *(Williams, 1975)* is given by equation 2.11

$$\mathbf{S = 11.8 * (Q_{surf} * q_{peak} * A_{hru})^{0.56} * K_{USLE} * LS_{USLE} * C_{USLE} * P_{USLE} * C_{FRG} \ldots 2.11}$$

Where;

S is the sediment yield on a given day in metric tons

Q_{surf} is the surface runoff from the watershed in mm/ha

q_{peak} is the peak runoff rate in m^3/s

A_{hru} is the area of HRU

KUSLE is the USLE soil erodibility factor

CUSLE is the USLE land cover and management factor

PUSLE is the USLE support practice factor

LSUSLE is the USLE topographic factor and

CFRG is the coarse fragment factor.

Soil Erodibility Factor (KUSLE)

Some soils erode more easily than others even when all other factors are the same. This difference is termed soil erodibility and is caused by the properties of the soil itself. (Wischmeier & Smith, 1978), define the soil erodibility factor as the soil loss rate per erosion index unit for a specified soil as measured on a unit plot. A unit plot is 22.1m (72.6-ft) long, with a uniform length-wise slope of 9%, in continuous fallow, tilled up and down the slope and its values range from 0 to 1.

Continuous fallow is defined as land that has been tilled and kept free of vegetation for more than two years. As noted that a soil type usually becomes less erodible with decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction or clay fraction

Cover and Management Factor (CUSLE)

Crop and management factor, C in the soil loss equation is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, Continuous fallow (Wischmeier and Smith, 1978). This factor measures the combined effect of all the interrelated cover and management variables. According to Morgan (1995) C factor represents the ratio of soil loss under a given crop to that of the bare soil.

Support practice factor (PUSLE)

P factor in the USLE is the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down-slope culture (tillage). It reflects the impact of support practices on the average annual erosion rate. As discussed by Mohammad et al., (2004) P factor indicates the fractional amount of erosion that occurs when any special practices are used compared with what would occur without them. The support practice affects erosion primarily by modifying the flow pattern, grade and direction of surface runoff and by reducing runoff amount and rate *(Lorenz and Schulze, 1995).* The P-factor value ranges from 0-1 depending on the soil management activities employed in the specific plot of land.

Topographic factor (LSUSLE)

The Slope Length Factor, L

In theory, the longer the slope, the more runoff will accumulate, gathering speed and gaining its own energy, causing rill erosion and then more serious gullying. However, Morgan (1995) found that the soil loss per unit area generally increases substantially as slope length increases. This means the greater accumulation of runoff on the longer slopes increases its detachment and transport capacities.

The Slope Gradient Factor, S

The slope-steepness factor, S is the ratio of soil loss from the field slope gradient to that from a 9-percent slope under otherwise identical conditions. As the gradient increases, the kinetic energy of rainfall remains constant, but transport accelerates toward the foot as the kinetic energy of the runoff increases and outweighs the kinetic energy of the rainfall when the slope (S) exceeds 15% (Wischmeier and Smith, 1978). It describes the soil erosion susceptibility of a given slope.

Routing face of the hydrological cycle

In SWAT water is routed though the channels network is using either the variable storage routing or Muskingum River routing methods. The details of the water routing methods are discussed in Neitsch et al., (2005). The sediment routing model Arnold et al., (1995) that simulates the sediment transport in the channel network, consists of two components operating simultaneously: deposition and degradation. To determine the deposition and degradation processes the maximum concentration of sediment calculated by equation 8 in the reach is compared to the concentration of sediment in the reach at the beginning of the time step. A brief description of sediment routing components of SWAT is given below (Neitsch et al., 2005).

The maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity and is calculated by equation 2.12

$$\mathbf{Conc_{sed,ch,mx}=C_{sp}.V_{ch,pk}{}^{Spexp}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{2.12}$$

In which concsed,ch,mx is the maximum con-centration of sediment that can be trans-ported by the water (ton/m3 or kg/l), C_{sp} is a coefficient defined by the user, $V_{ch,pk}$ is the peak channel velocity (m/s), and S_{pexp} is exponent parameter for calculating sediment reentrant in channel sediment routing that is defined by the user. It normally varies between 1.0 and 2.0.

The amount of sediment degradation in the channel can be calculated by the model by using equation 2.13 and the net amount of sediment deposited in the reach segment is calculated by equation 2.14

$$\mathbf{Sed_{deg} = (Conc_{sed,ch,mx} - Conc_{sed.ch.j}) * V_{ch} * K_{ch} * C_{ch}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.13$$

$$\mathbf{Sed_{dep} = (Conc_{sed,ch,i} - Conc_{mx}) * V_{ch}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{2.14}$$

Where: Sed_{deg} is the amount of sediment re-entrained in the reach segment (metric tons), $Conc_{sed,ch,i}$ is the amount of initial sediment concentration in the reach (kg/l or ton/m3), $Conc_{sed,ch,mx}$ is the maximum concentration of sediment that can be transported by the water (kg/l or ton/m3), Kch is the channel erodibility factor (cm/hr/pa), Cch is the channel cover factor and Vch is the volume of water in the reach segment (m3), Sed dep is the amount of sediment deposited in the reach (metric tons).

The final amount of sediment in the reach is determined from equation 2.15;

$$\mathbf{Sed_{ch} = (Sed_{ch,i} - Sed_{dep}) + Sed_{dep}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{2.15}$$

In which Sed_{ch} is the amount of suspended sediment in the reach (metric tons), $sed_{ch,i}$ is the amount of suspended sediment in the reach at the beginning of the time period (metric tons).

The amount of sediment transported out of the reach is calculated by equation 2.16;

$$\mathbf{Sed_{out} = Sed_{ch} * \frac{Vout}{V}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{2.16}$$

In which Sed_{out} is the amount of sediment transported out of the reach (metric tons), V_{out} is the volume of outflow during the time step (m^3).

Sediment lags in Surface Runoff

In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff will reach the main channel on the day it is generated and also Sediment in the surface runoff is lagged as well. SWAT incorporates a surface runoff storage feature to lag part of the surface runoff release to the main channel. Once surface runoff is calculated, the amount of surface runoff released to the main channel is calculated by equation 2.17 and after the sediment load in surface runoff is calculated, the amount of sediment released to the main channel is calculated using equation 2.18 by the model

$$Q_{surf} = (Q'_{surf} + Q_{stor\ j-1})\left(1 - \exp\left[\frac{-Sur\ lag}{t_{conc}}\right]\right) \quad \ldots\ldots\ldots\ldots\ldots 2.17$$

$$Sed = (Sed' + Sed_{stor\ j-1})\left(1 - \exp\left[\frac{-Sur\ lag}{t_{conc}}\right]\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots 2.18$$

Where: Q_{surf} is amount of surface runoff discharged to main channel in a day (mm), Q' is amount of surface runoff generated in a sub basin in a day (mm), Q_{stor}, i-1 is the surface runoff stored or lagged from the previous day (mm), Sur lag is the surface runoff lag coefficient, t_{conc} is the time of concentration for the sub basin (hrs) and in equation 2.14, Sed is the amount of sediment discharged to the main channel on a given day (metric tons), Sed' is the amount of sediment load generated in the HRU on a given day (metric tons), $Sed_{stor,\ i-1}$ is sediment stored or lagged from the previous day (metric tons)

Sediment in lateral and ground water flow

Even though, it is small in proportion to the surface flow contribution, SWAT allows the lateral and groundwater flow to contribute sediment to the main channel and calculated By equation 2.19

$$Sed_{lat} = \frac{((Q\ lat + Qgw) * Area_{HRU} * Conc\ sed)}{1000} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.19$$

Where Sed_{lat} is the sediment loading in lateral and ground water flow (metric tons), Q_{lat} is the lateral flow for a given day (mm water), Q_{gw} is the groundwater flow for a given day (mm water), Area HRU is the area of the HRU (km^2), $Conc_{sed}$ is the concentration of sediment in lateral and groundwater flow (mg/l).

2.3.5 SWAT strength and limitation

Strength

- Watersheds with no hydrology monitoring data (e.g., stream gage or water quality data) can be modeled.
- Modeling based on physical processes associated with soil and water interaction
- Capability of modeling the changes in land use and management practices
- The model uses readily available inputs. While SWAT can be used to study more specialized processes such as bacteria transport, the minimum data required to run the model are commonly available from government agencies.
- SWAT is computationally efficient. Simulation of very large basins or a variety of management strategies and also Capable of long term simulations
- The model is designed to use either observed meteorological data or statistically generated meteorology.
- The model is freely available and can be easily downloaded from the internet.

Limitation

- SWAT contains many processes; certain processes may still not be well represented. For example, Ndomba and van Griensven (2011) indicated in their paper that certain landscape elements, such as wetlands, are not well represented in the SWAT model, while they may have a huge impact on the hydrological and nutrient cycle.
- Due to the heterogeneity of the catchments, a number of meteorological observation stations are required to represent the spatial variation in the hydro meteorological characteristics in the area. The lack of adequate number of observation stations affects the model output.
- In order to represent the spatial variation in the catchments characteristics, GIS software is the pre-requisite to run the model.
- The MUSLE approach is most applicable to the estimation of cumulative loads, rather than loads from individual events. It should also be noted that the default SWAT algorithm may yield unrealistic results from HRUs that contain a mix of urban pervious and impervious land cover because MUSLE is calculated with the peak flow.
- SWAT model are generally applicable all over the globe. Several of these processes have an empirical background whereby the equations were derived from large data sets in the US. They used curve number approach and the USLE soil loss equations are good examples.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of study area

3.3.1 Location

In the central sector of the main Ethiopia rift, the ziway-shala lake basin system includes four present day residual lakes, from north to south, lakes Ziway, Langano, Abijiata and Shala. The study area is the northern part of Central Ethiopian Rift Valley catchment; located partly in Oromia and partly in Southern Nations and Nationality states.

Katar River is a river of central Ethiopia. It arises from the glaciated slopes of Mount Kaka and Mount Badda in the Arsi Zone. One of the Katar's tributariy is the Gonde.

Katar watershed covers 3338.4 square kilometres (km^2) is part of the Ziway– Shala basin, an internal drainage basin located in the central part of the Main Ethiopian Rift Valley (Figure 2.1). Geographically it is located between 7°21'33"–8°9'53" north of latitude and 38°53'57"–39°24'46" east of longitude.. Katar River and its tributaries drain from south east highland area to North West and enter Lake Ziway. This lake is the most northerly of the Main Ethiopian Rift Valley lakes, and is fed principally by rivers draining the south eastern and north western plateaux and escarpments. The over flow of Lake Ziway feeds Lake Abiyata to the south.

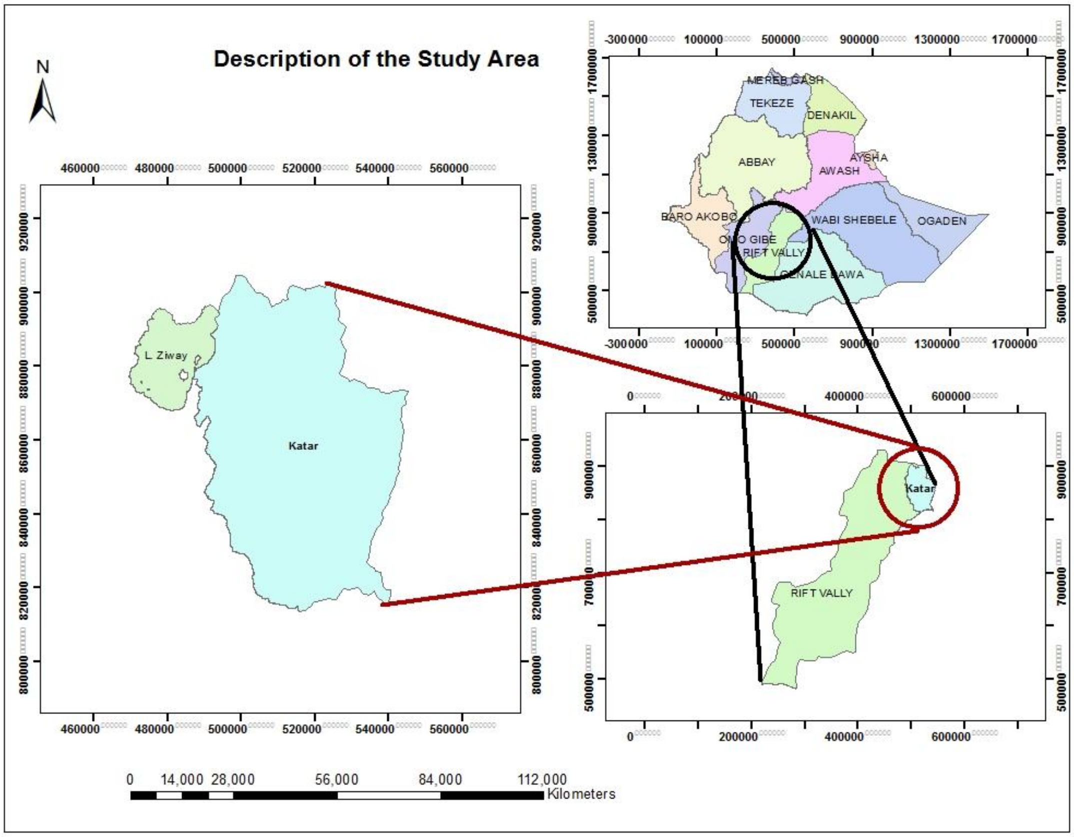


Figure 3.1 Location Map of Katar Watershed

3.3.2. Topography

In the study area, the MER is bounded by steep border fault escarpments 70-80 km apart, limiting the country plateau to the west and to the east.

The Katar catchment shows a well pronounced variation with the altitude ranging from around 1646 masl near Lake Ziway (at the outlet) to about 4171 m asl, on the high volcanic ridges along the eastern watershed. The gradient of the Katar river is generally steep through its course to Lake Ziway, and it is often deeply incised up to 50 m below the surrounding countryside.

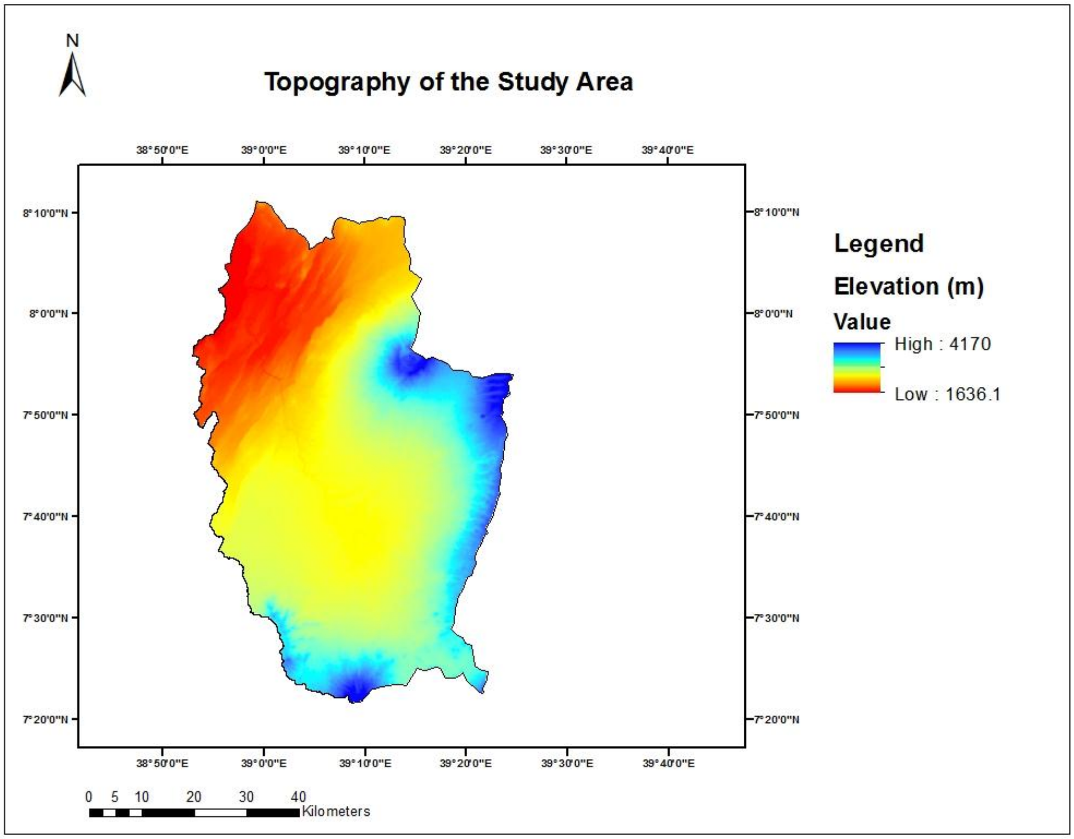


Figure 3.2 Topography of Katar Watershed

3.3.3. Climate

The rainfall regimes and seasons in Ethiopia are diverse. According to *(NSA 1996, Halcrow 2008)* gives four rainfall regimes in the country: mono-modal, bimodal type I, bimodal type II, and diffused pattern. Based upon this, generally the following seasons have been defined with local name for the study area: -

a) Kiremt – the main rainy season that covers the period from June to September (75% of the annual total has fallen at Ziway by mid-August).

The air flow during this season is dominated by a zone of convergence in low pressure systems accompanied by the oscillatory Inter Tropical Convergence Zone (ITCZ) extending from West Africa through north of Ethiopia towards India. The rain represents 50-70% of the average year total *(Degefu 1987, D. Legesse, A. Abiye, C. Vallet-Coulomb, and H. Abate,2010).*

b) Bega - Generally dry season that covers the period from October to first February. But, there is occasionally untimely rain. During this season, the country predominantly falls under the influence of warm and cool north-easterly winds. These dry air masses originate either from the Saharan anticyclone and / or from the ridge of high pressure extending into Arabia from large high over central Asia (Siberia). The rain which occurred in this season covers 10-20% of yearly average *(Degefu 1987, D. Legesse, A. Abiye, C. Vallet-Coulomb, and H. Abate,2010).*

c) Belg - small rainy season accounting for 20-30% of the annual amount that covers the period from mid-February to mid-May. However, the rainfall is highly characterized by inter-annual and inter-seasonal variations. This season coincides with domination of the Arabian high as it moves toward the North Arabian Sea.

According Makin M.J. et al (1975), climate of the study area consists of three ecological zones: humid to dry humid lands, dry sub-humid or semi-arid lands and semiarid or arid lands. The average annual rainfall of the area varies spatially from about 650mm in rift floor to over 1200mm at extreme highland areas. The mean annual temperature also varies between 15^0C in the highlands and 20^0C in the rift.

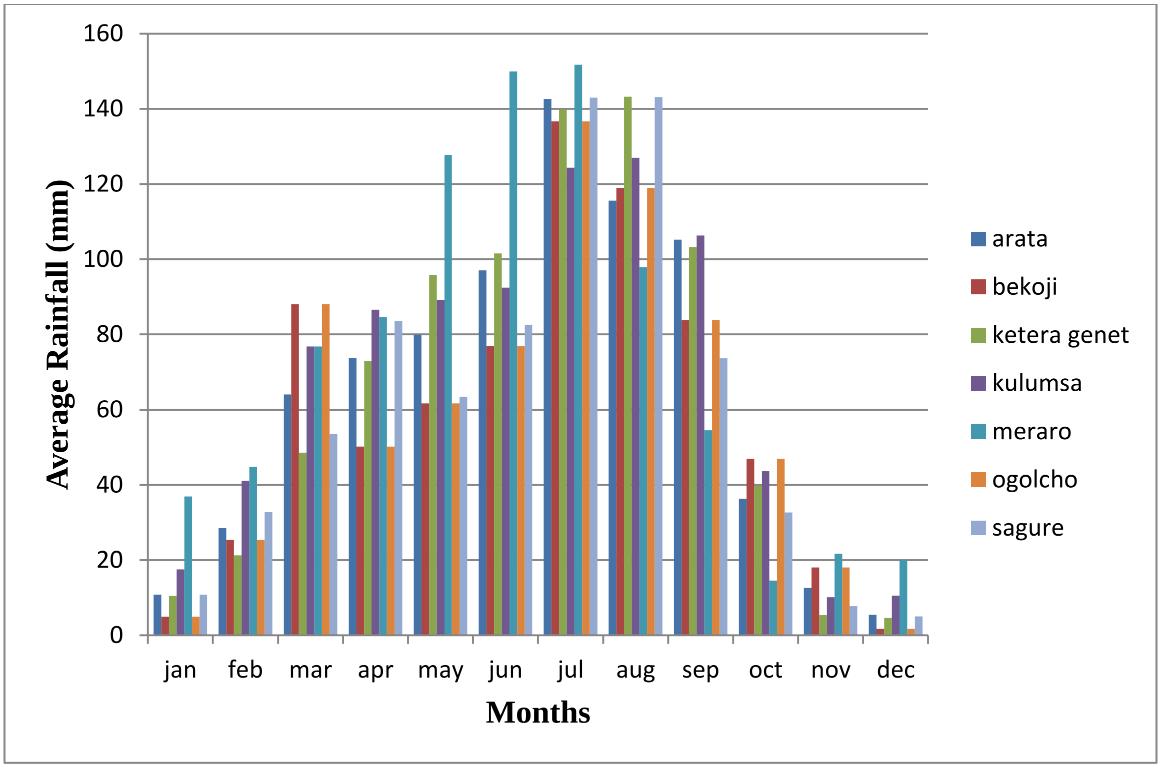


Figure 3.3: Mean monthly Rainfalls in Katar Watershed (Source:NMA)

3.3.4. Land Use and Land Cover

The land cover of the study area has made dramatic change with the past years as a result of an outspread of agricultural land, settlement of population and reduction of forest land and also grass land (Damtew F, 2015).

The low-lying region around Lake Ziway is typically of semi-arid land characterized by dry land acacia. Much of the higher escarpments below 3000 m are either cultivated or under grass. With increasing altitude, the catchment is mainly characterized by traditionally cultivated /pasture land with wheat and barley being the major crops, together with some oil crops, peas and ‘false banana’ Ensete verticosum (a staple food in many parts of the catchment and cultivated at altitudes ranging between 1600 and 3000 m).(D. Derege, 2005).

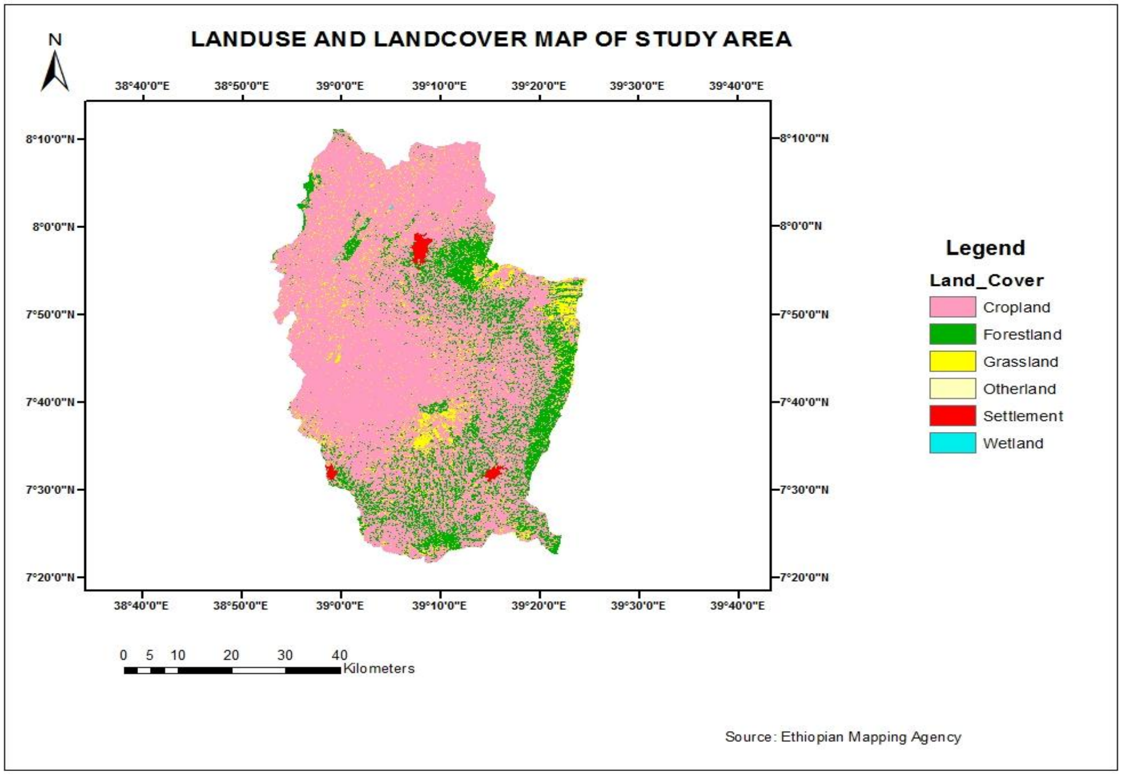


Figure 3.4: Land use and Land Cover Map of Katar Watershed

Table 3.1: Land use and Land Coverage on study Area.(Source: EMA)

No	Land use and Land cover	Area in Km^2	Coverage (%)
1	Forest land	6,0491.31	18.1
2	Grass land	21,965.97	6.5
3	Cropland	249,341.85	74.6
4	Wetland	129.70	0.03
5	settlement	1912.56	0.57
Total		3338.41	100

3.3.5. Soil type

Soil type of study area is closely related to parent material and degree of weathering (Makin et al 1976). The main parent materials are basalt, acidic lava, ignimbrite, volcanic ash, pumice, riverine and lacustrine alluvium *(GM Di paola,1972).* Weathering varies from deeply weathered basalt in humid highland areas to unweather recent alluvial deposits in the drier central part of the rift valley *(Alemu D,2006).*

Generally the dominant soil types of the study area are *vertic cambisols, pellic vertisol,chromic luvisols, ,eutric fluvisols,eutric cambisols, orthic luvisols,vitric andosols,eutric nitisols,dystric nitisols and mollic andosols*. The spatial distribution of the dominate soil types is shown in figure 2.5. The soil data for the study area was found from MoWIE.

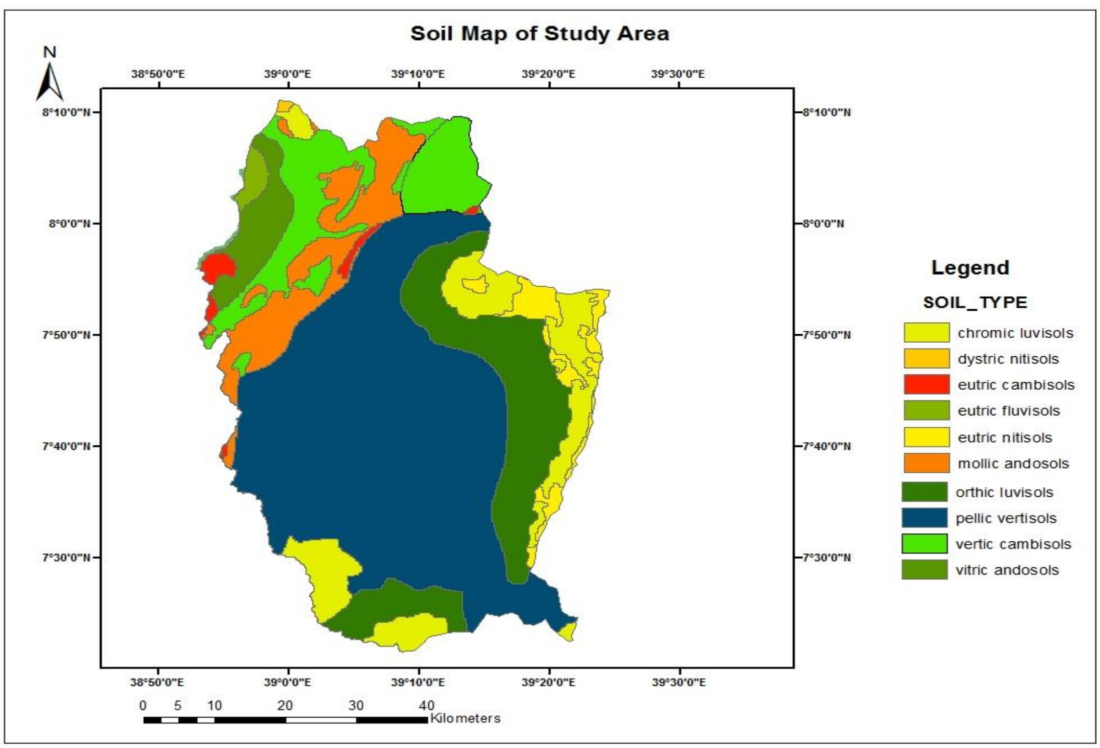


Figure 3.5 Soil Map of the Katar Watershed

Table 3.2: Soil Distribution in Katar Watershed. (Source:MoWIE)

No	Soil_Type	Area in Km^2	Coverage (%)
1	Chromic luvisols	354.52	9.90
2	Dystric nitisols	3.42	0.10
3	Eutric cambisols	38.62	1.08
4	Eutric fluvisols	27.55	0.77
5	Eutric nitisols	108.06	3.02
6	Mollic andosols	315.37	8.81
7	Orthic luvisols	536.95	15.00
8	Pellic vertisols	1670.79	46.67
9	Vertic cambisols	156.95	4.7
10	Vitric andosols	126.19	3.52
	Total	3338.41	100.00

3.2 Methodology

The steps used for the research are:-

- First, data collection: - can be classified into spatial and temporal data. Spatial data used are DEM, land use/cover and soil map of the study area.
- Second, the temporal data are Metrological and hydrological data, which swat simulation run of stream flow for these set of variables (i.e topography, climate data, LULC, soil) and sensitivity analysis was conducted to identify the most sensitive flow parameter that affected stream flow.
- Third, performance evaluation of SWAT model was undertaken through Calibration and validation step using measured and simulated stream discharge on monthly basis and simulation run for the response of stream flow based on calibrated parameter.
- Fourth, similar as third step , the performance evaluation of SWAT model was carry out through Calibration and validation step using measured and simulated sediment transport on monthly basis and simulation run for the response of sediment based on calibrated parameter.

The conceptual frame work (Figure 3.6) which present on below, serves to describe the overall research steps describing the methodology applied to carry out the research.

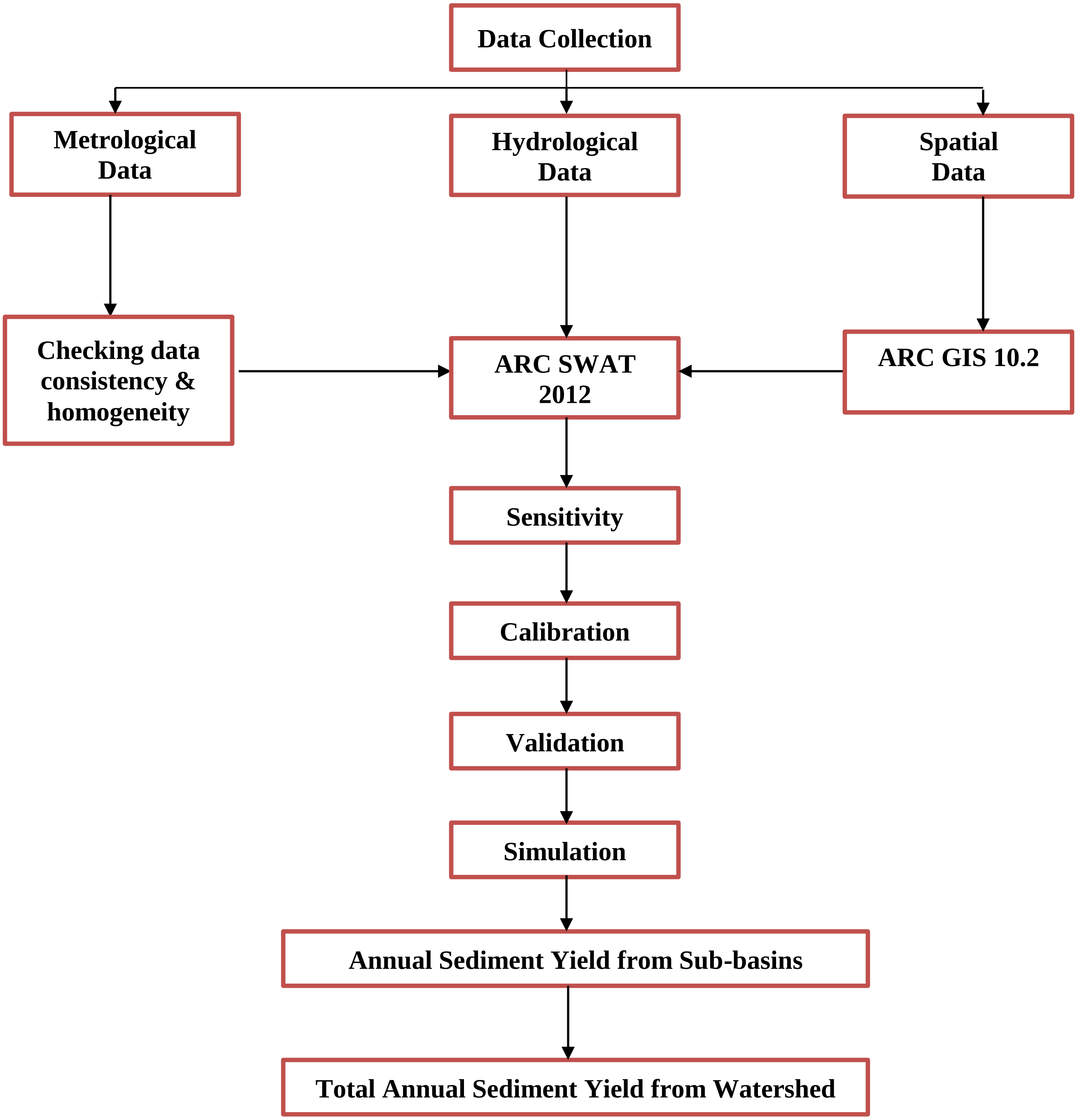


Figure 3.6 Frame Work of the research

3.3 SWAT Input

3.3.1 Digital elevation model (DEM)

The digital elevation model (DEM) is any digital representation of a topographic surface which describes the elevation of any point in a given area at a specific spatial resolution as a digital file and it is specifically made available in the form of raster or regular grid of spot heights. It is the basic input of SWAT to delineate the watershed in to a number of sub watersheds or sub basins. DEM is used to analyze the drainage pattern of the watershed, slope, stream length, width of channel with in the watershed.

The katar River watershed was delineated and River networks were generated from ASTER DEM. The digital elevation model used in this study has a resolution of 90m*90m was obtained from the WWDSE office, The raw DEM was processed by Global mapper to bound the study area & projected using ARCGIS 10.2 & Arc Map 10.2.2 version software package. The projected coordinate system parameters of study area are: UTM— WGS 1984—zone 37N.prj.

3.3.2 Land use and Land cover

Spatial distribution and specific land use parameters were required for modeling. Land use / Land cover are the second spatial input data required by SWAT model. Land use is one of the most important factors that affect runoff, evapotranspiration and surface erosion in a watershed. Land use/ Land cover data were collected from Ethiopia Mapping Agency and the reclassification of the land use map was done to represent the land use according to the specific land cover types as shown on figure 3.4 of the study area LULC map. A look up table that identifies the 4-letter SWAT code for the different categories of land use/land cover were prepared so as to relate the grid values to SWAT land cover/land use classes.

Table 3.3: Land use/ land cover types in the study area and corresponding SWAT value

Original land use	Corresponding SWAT Definition	SWAT Code
Forestland	Forest-Evergreen	FRSE
Cropland	Agricultural Land-Row Crops	AGRL
Grassland	Pasture	PAST
Settlement	Residential-Medium Density	URMD
Wetland	Wetlands-Mixed	WETL

3.3.3 Soil data

SWAT model requires different soil textural and physicochemical properties such as, soil layer, soil texture, soil depth, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. These data were obtained mainly from Ministry of Water, Irrigation and Electricity office (hydrology section), Digital Soil Map of the country and Derived Soil legend of FAO (1998). Major soil types in the watershed are shown on figure 3.5 and the detailed property for each soil type of the study area were gathered from WWDSE hydrology section, FAO database (FAO 2002) And from the model called Soil-plant-Atmosphere-Water field and pond hydrology (SPAW).Detail in Appendix IV.

3.3.4 Meteorological data

Meteorological data is needed by the SWAT model to simulate the hydrological conditions of the basin. The most important input climatic parameters used in the SWAT modeling includes, precipitation, maximum and minimum temperature, humidity, solar radiation and wind on daily time series from 1985-2015 year of seven stations (Arata, Bekoji, Kulumsa, ketera Genet, Ogolcho, Sagure and meraro) found within the watershed were obtained from National Meteorology Agency of Ethiopia (NMAE). The stations were selected because of the proximity to the study area and also Thiessen polygon method was conducted to check whether they are influential for the study area. For SWAT model, the records of precipitation and temperature are the minimum mandatory inputs and the other parameters are optional. The model has the capability of weather generation to itself generate the data against these parameters. All the missing values of the data encode with -99.0.All input climatic data were prepared in text format to append in the model. The map of Rainfall station are shown Annex VI.

Table 3.4 The available climatic data of the station

Name of stations	precipitation	Max & min temperature	Relative humidity	Sunshine hour	Wind speed
Arata	✓	✓	-	-	-
Bekoji	✓	✓	-	-	-
Kulumsa	✓	✓	✓	✓	✓
Ketera Genet	✓	-	-	-	-
Ogolcho	✓	✓	-	-	-
Sagure	✓	✓	-	-	-
Meraro	✓	✓	✓	✓	✓

3.3.5 Hydrological data

The hydrological data was required for performing sensitivity analysis, calibration and uncertainty analysis and validation of the model. The hydrological data was also collected from ministry of Water, Irrigation and Electricity department of hydrology from 1980-2012 G.C. The hydrological data collected was daily flow for the Katar river feeding into Lake Ziway at Abura flow station (8.04 LAT, 39.03 LONG). It was the only hydrological data used for sensitivity analysis, calibration and validation because of it has long term and reliable stream flow data and also located near the outlet of river to the lake. Detail in Appendix III

Sediment Data

There are few sediment data which have measured suspended sediment data in the Katar River for 2 years only 1992 and 2005 G.C. (see table 3.5). Depending on the observed suspended sediment data the remaining values were generated from sediment rating curve for calibration and sensitivity analysis.

The sediment rating curve is a relationship between the river discharge and sediment concentration or load (Clarke, 1994). It is widely used to estimate the sediment load being transported by a river. Generally, a sediment rating curve may be plotted showing average sediment concentration or load as a function of discharge averaged over daily, monthly or other time periods. So that using rating curve, the records of discharges are transformed into records of sediment concentration or load. Commonly, the relation is the following form:

$$C = a\,Q^{b} \qquad \text{……………………………}3.1$$

Suspended sediment concentration (mg/l),Q is the discharge (m^3/s), a and b are constants. The most commonly used sediment rating curve is power function (walling,1974; walling 1978).

The Sediment flow measurement in the Katar River was not in continuous time step; so that by using stream flow and measured sediment data can generate sediment rating curve. The measured suspended sediment concentration data of Katar River is as shown below.

Table 3.5: Suspended Sediment Data from MoWIE

Station no.	**River / Stream**	**Basin**	**Date of Sampling**	**Flow (m^3/s)**	**Depth (m)**	**Sediment load (tons/day)**
81019	Katar	Rift Valley	21-Nov-92	4.141	0.52	77.37
81019	Katar	Rift Valley	21-Nov-92	4.141	0.88	183.08
81019	Katar	Rift Valley	23-Jun-05	1.226	0.62	15.27
81019	Katar	Rift Valley	23-Jun-05	1.226	0.52	13.96
81019	Katar	Rift Valley	23-Jun-05	1.226	0.40	11.86

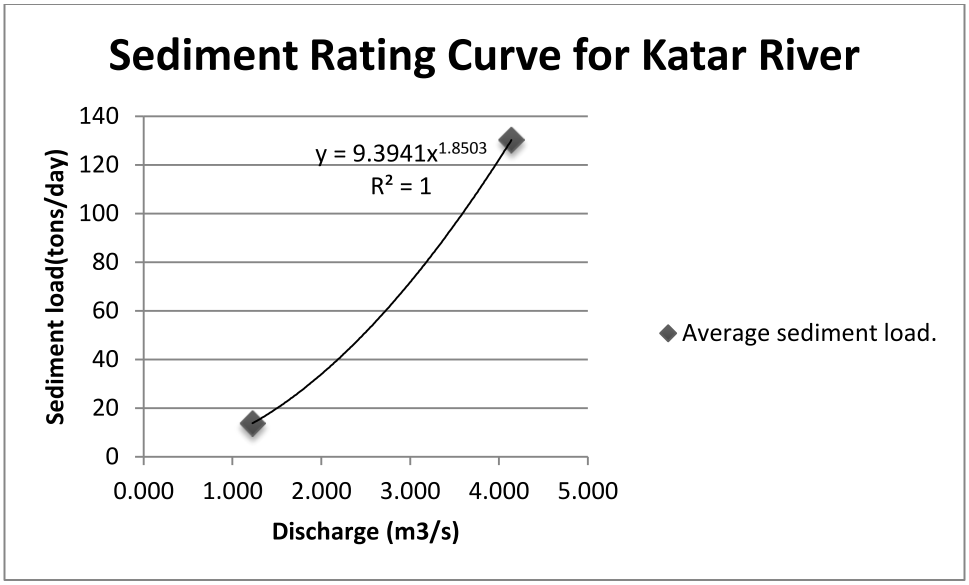


Figure 3.7 Sediment Rating curve for the Katar River

3.3.6 Filling Missing Weather Data

To generate the missing weather data, SWAT includes the WXGEN weather generator model *(Neitsch, et al, 2001)* that generates the climatic data and fill-in gaps in measured records. The weather generator requires the daily values of all climatic variables from measured data or generated from values using monthly average data over a number of years. The weather input variables required included; Solar radiation, wind speed, relative humidity, precipitation, dew point, minimum and maximum temperatures. But from NMAE we only directly gathered four of the variables excluding solar radiation and dew point.

Solar radiation

As a consequence of, NMAE is not directly measured solar radiation instead the sunshine hour data is found, it can be calculated with the Angstrom formula which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \quad \text{..................................}\mathbf{3.2}$$

Where;

R_s solar or shortwave radiation [MJ m-2 day-1],

n actual duration of sunshine [hour],

N maximum possible duration of sunshine or daylight hours [hour],

n/N relative sunshine duration [-],

R_a extraterrestrial radiation [MJ m-2 day-1],

a_s regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0),

a_s+b_s fraction of extraterrestrial radiation reaching the earth on clear days (n = N).

Depending on atmospheric conditions (humidity, dust) and solar declination (latitude and month), the Angstrom values a_s and b_s will vary. Where no actual solar radiation data are available and no calibration has been carried out for improved as and bs parameters, the values $a_s = 0.25$ and $b_s = 0.50$ are recommended.

The daylight hours, N, and the extraterrestrial radiation, $R_{a,}$ they have their own calculation method which found in FAO website meteorological data.html in title of Crop evapotranspiration - Guidelines for computing crop water requirements.

Dew point calculation

The saturation vapor pressure e_s were derived from the daily air temperature values T (equation 3.3). After that, the actual average daily vapor pressure e_a was calculated using saturation vapor pressure e_s and average humidity data (RH) equation 3.4. According to Allen, (1998):

$$e_s = 0.6108 * \exp((1\ 7.27 * T) / (T + 237.3)) \ldots\ldots\ldots\ldots..3.3$$

The unit for saturation vapor pressure generated by equation 4.5 is [kPa] and Kpa * 10 is equal to mbar. According to Hackel, (1999):

$$e_a = RH*e_s / 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.4$$

The daily dew point temperature was calculated using equation 3.5.

$$Dew = (234.18 * 1og_{10}(e_s) - 184.2) / (8.204 - \log_{10}(e_s)) \ldots\ldots3.5$$

Where Dew = dew point temperature [°C], e_s = saturation vapour pressure [mbar], e_a = actual vapor pressure [mbar], exp = 2.7183 (base of natural logarithm), T = air temperature [°C] and RH = relative humidity [%].

Using daily minimum and maximum temperature data, the saturation vapor pressure were derived twice (e_{smin} and e_{smax}) according to equation 3.3. In this case the saturation vapour pressure used by equation 3.4 was the mean value of e_{smin} and e_{smax}.

For this study, the selected weather generator stations (station used for infilling of missing data) were Kulumsa, and Meraro stations due to the availability of data. They are class A meteorological stations. To generate the data, weather parameters values were developed by using WGN maker 4.1 (Excel Macro Solver) which would eventually use by the built in a weather generator WXGEN in the SWAT input file for filling missing daily values. Appendix VII

3.3.7 Checking the Stationary and Relative Consistency

Detection of trends in long time series of hydrological data is of paramount scientific and practical significance. Engineering studies of water resources development and management depend heavily on hydrological data. These data should be stationary, consistent, and homogeneous when they are used for frequency analyses or to simulate a hydrological system. To determine whether the data meet these criteria, the engineer needs a simple but efficient screening procedure.

A time series of hydrological data may exhibit jumps and trends owing to what Yevjevich and Jeng (1969) call inconsistency and non-homogeneity. **Inconsistency** is a change in the amount of systematic error associated with the recording of data. It can arise from the use of different instruments and methods of observation. **Non homogeneity** is a change in the statistical properties of the time series. Its causes can be either natural or man-made. These include alterations to land use, relocation of the observation station, and implementation of flow diversions.

The data screening procedure consists of four principal steps. These are:

- A rough screening of the data from the selected rainfall years for the study and compute the monthly totals for the hydrological season.
- Plotting these totals according to the monthly time step and
- Test the time series for absence of trend with Spearman's rank-correlation method
- Apply the F-test for stability of variance and the t-test for stability of mean
- And finally, test the time series for relative consistency and homogeneity with double-mass curve method (this method verify only relative consistency and homogeneity, it cannot verify stationary). Detail in Appendix II

The result of those analysis revealed that the seven metrological stations used for this study, which are Arata, Bekoji, Kulumsa, ketera Genet, Ogolcho, Sagure and meraro, are consistent and homogeneous.

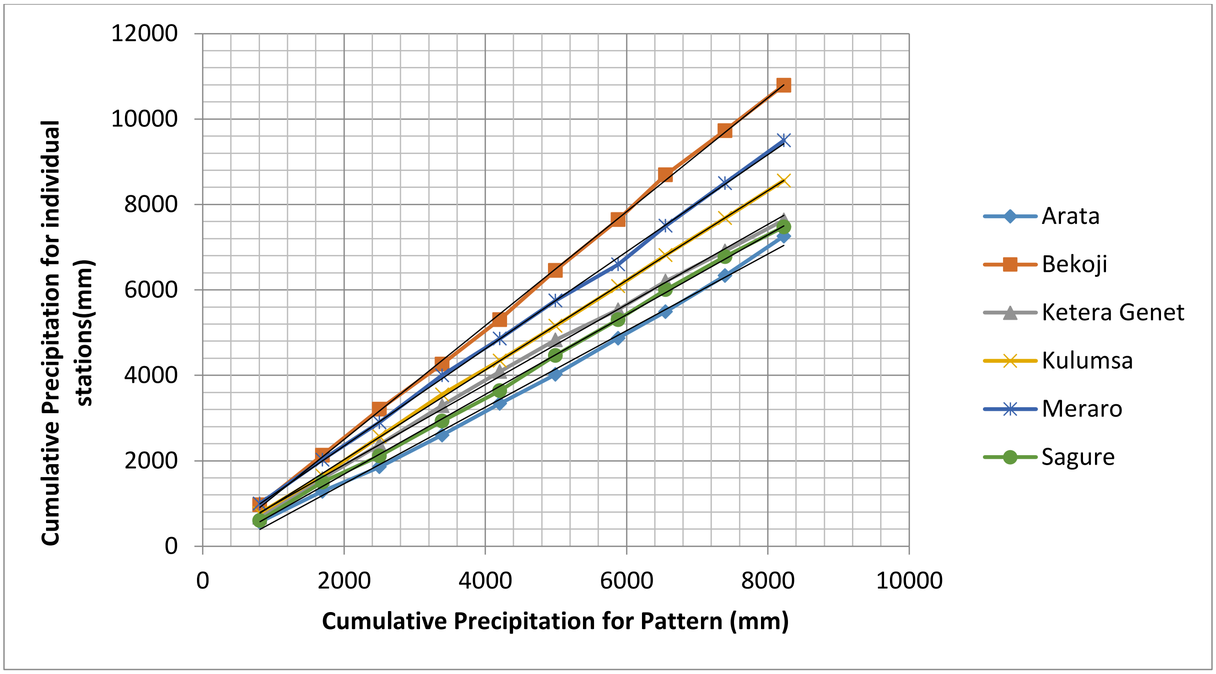


Figure 3.8 Double mass curve for this specific study.

3.4 Arc SWAT Model Setup

3.4.1 Watershed delineation

The first step in model set up was creating the new SWAT project in ArcSWAT. Then The required spatial datasets were projected to the projection type called WGS_1984_UTM_Zone_37N, Using ArcGIS 10.2. The DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. The initial stream network and sub-basin outlets were defined based on drainage area threshold approach. The threshold area defines the minimum drainage area required to form the origin of a stream and to define the minimum size of the sub basin by deciding the initial threshold area (TA). Besides those sub-basin outlets created by the interface, outlets were also manually added at the outlet of the watershed (inlet of lake Ziway). Next the area of interest was delineated by selecting a point at the added outlet of the watershed and found to be 3338.4 km^2.The drainage networks; flow accumulation and flow direction all were automatically processed in Arc SWAT and delineate the watershed. Total 21 sub basins were delineated by SWAT for Katar watershed by calculating the geomorphologic sub-basin parameter.

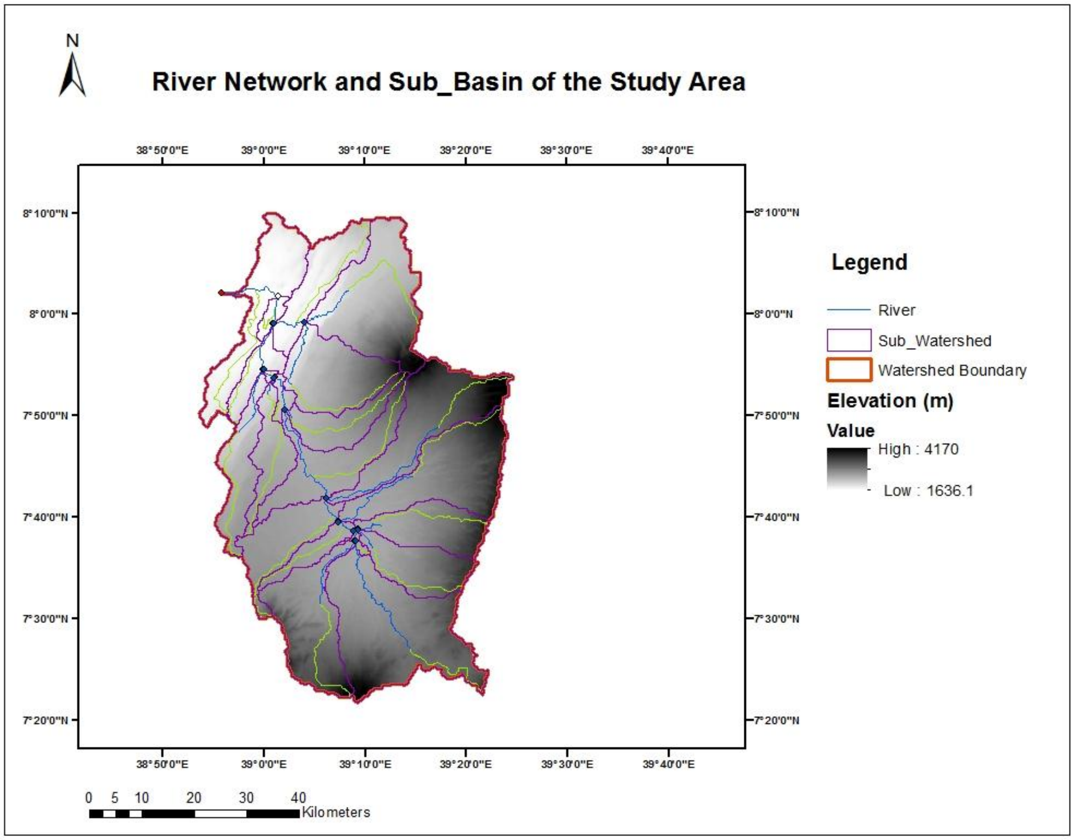


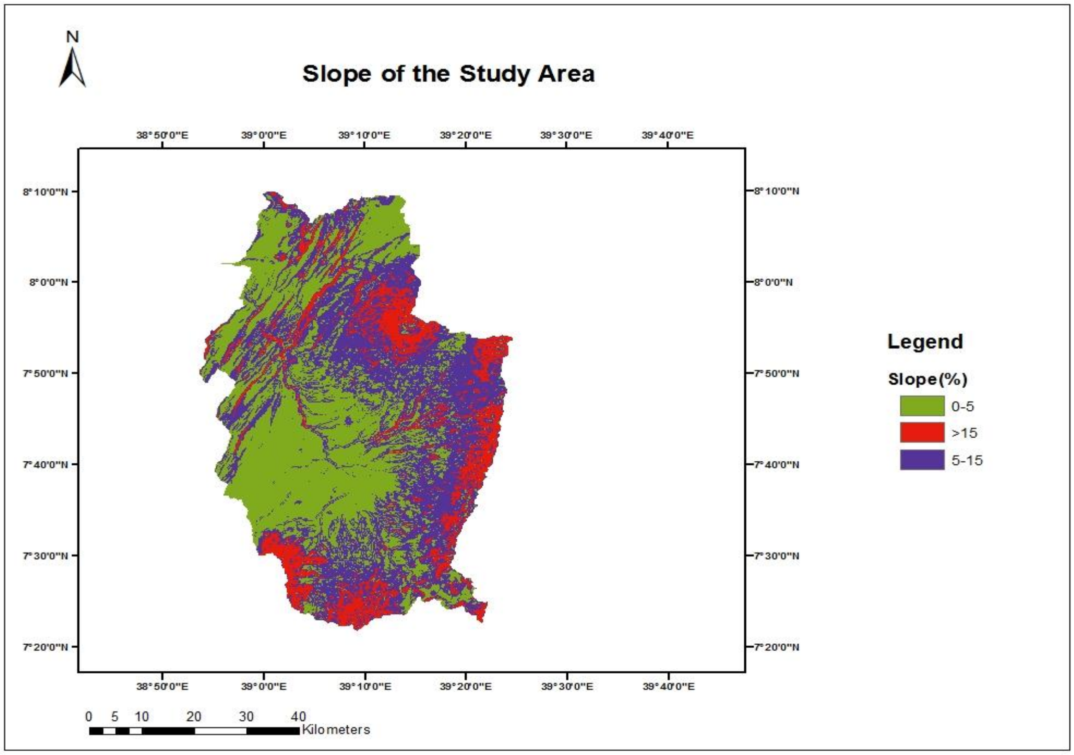
Figure 3.9 River Network of the study area (SWAT model)

3.4.2 Hydrologic response unit analysis

Subdividing the sub watershed into areas having unique land use, soil and slope combinations makes it possible to study the differences in hydrologic conditions for different land covers, soils and slopes. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy in flow prediction and provides a much better physical description of the water balance.

Land use and soil map were prepared Using ArcGIS 10.2 in polygon shape format and imported in to the Arc SWAT model in a projected type similar as the DEM to determine the area and hydrologic parameters of each land-soil category simulated within each sub-watershed. Spatial distribution and specific land use parameters were required for modeling. SWAT has predefined land uses identified by four letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interface. Hence, while preparing the lookup table, the land use types were made compatible with the input needs of the model as shown on Table 4.1.Hence the classified land use map and its attribute were adjusted to the SWAT model requirement format and database. Agricultural land use is the dominant land use in the Katar River catchment. As that of the land use, the soil layer in the map should linked to the user soil database of the model, unlikely, the soil types found in the catchment is not found in U.S database. So that, SWAT does not recognize the Stmuid of the soil map. Therefore to classify the soils, new soils and their properties were added to the soil database.The soil characteristics were entered manually. To facilitate their Manipulation they were rearranged in an EXCEL table and introduced to user soil database of the model.

In the third step of land use/soil/slope definition, the land slope classes were integrated in defining the hydrologic response units. The DEM data used during the watershed delineation was also used for slope classification. The multiple slope discretization operation was preferred over the single slope discretization as the sub-basins have a wide range of slopes between them. Based on the suggestion, three slope classes (0-5, 5-15 and >15) were applied and slope grids reclassified. Then land use, soil and slope grids were overlaid as shown on figure 3.



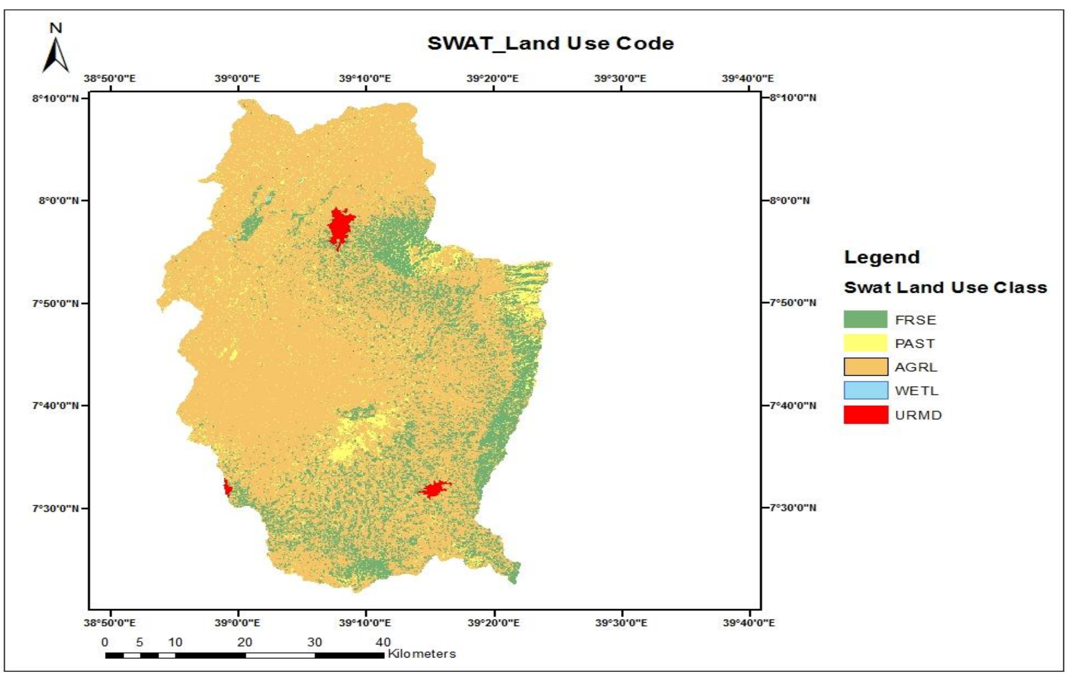


Figure 3.10 land use and slope classification of the study area in SWAT model.

The last step in the HRU analysis was the HRU definition. There have two options in determining the HRU distribution: assign a single HRU to each sub watershed or assign multiple HRUs to each sub watershed. If a single HRU per sub basin is selected, the HRU is determined by the dominant land use category, soil type, and slope class within each watershed. If multiple HRUs are selected, the user may specify sensitivities for the land use, soil, and slope data that will be used to determine the number and kind of HRUs in each watershed. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Land uses, soils or slope classes which cover less than the threshold level were eliminated and the area of the remaining land use, soil, or slope class was reapportioned so that 100% of the land area in the sub-basin was modeled. The threshold levels set is a function of the project goal and amount of detail required. Hence, taking 5%, 20%, and 20% threshold levels for the land use, soil and slope classes respectively was selected for this study by considering the effect on the formulation of hydrologic response and for making the HRU formulation in a manageable amount. A total of 156 HRUs were defined for the whole catchment.

3.4.3 Importing climate data

After HRUs are defined, the next step in model set up is importing the climate data. Climate data is one of the main sets of input for simulating the hydrological processes in SWAT which helps to provide the moisture and energy inputs that control the water balance and determine the relative importance of the different components of the water cycle. The climatic variables required by SWAT daily precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity were prepared in the appropriate text (.txt) format together with their weather location and imported in to the SWAT model. Then the SWAT input tables were written into the model.

3.4.4 Simulation approach

After the model setup, the simulation of SWAT was executed with the following options: (1) the Runoff Curve Number method for estimating surface runoff from precipitation, (2) the Penman-Monteith for estimating potential evapotranspiration generation, and (3) the Variable storage method is used to simulate channel water routing. Finally, the model was run for the year 1985 to 2015 by fixing the warm up period of three years.

The result from the simulation cannot be directly used for further analysis. Instead, the ability of the model to sufficiently predict the constituent stream flow and sediment yield should be evaluated through sensitivity analysis, model calibration and model validation *(White & Chaubey, 2005).*

3.5 Model Calibration, validation and sensitivity analysis.

3.5.1 Sensitivity analysis

A complex hydrologic model is generally characterized by a multitude of parameters. Most of the values of these parameters are not exactly known. This can be for many reasons. Spatial variability, measurement error, incompleteness in description of both the elements and processes present in the system are some of the reasons (Holvoet et al., 2005). Therefore, Over-parameterization is a well-known and often described problem in hydrological models, especially for distributed models such as SWAT. An analysis of determining the rate of change in model output with respect to changes in model inputs (parameters) is called sensitivity analysis (Abbaspour, 2013). These methods identify parameters that do or do not have a significant influence on model simulations of measured observations for specific catchments. In addition sensitivity analysis is useful not only for model development, but also for model validation and reduction of uncertainty (Hamby, 1994 cited in Lenhart et al. 2002).

Generally, identifying sensitive parameters prior to model calibration helps to allow the possible reduction in the number of parameters that must be calibrated thereby reducing the computational time required for model calibration. Once the sensitivity analysis is done calibration can be performed for limited number of influential parameters.

The current version of SWAT model, SWAT 2012, provides the algorithmic techniques for calibration, validation and sensitivity analysis interrelated with SWAT-CUP program. SWAT-CUP (Calibration and Uncertainty Procedures) (Abbaspour et al., 2014) is a standalone program developed for calibration, validation and sensitivity analysis of SWAT models.

The program contains five different calibration procedures and includes functionalities for validation and sensitivity analysis, SUFI-2, PARASOL, GLUE, McMc and PSO.

In this study, we used the program SUFI-2 for model calibration, validation and sensitivity analysis. The program is semi-automated, meaning that some steps during the calibration process the user need to do manually. For time-consuming large-scale models, SUFI-2 was found to be quite efficient (Yang,et al., 2008).

Two types of sensitivity analysis are allowed when using SUFI 2 (Sequential Uncertainty Fitting version 2).Global Sensitivity and One-at-a-time sensitivity analysis. Here, we examine the results of the global sensitivity analysis performed in the program.

Global sensitivity analysis performs the sensitivity of one parameter while the value of other related parameters are also changing. Global sensitivity analysis uses t-test and p-values to determine the sensitivity of each parameter. The t-stat provides a measure of the sensitivity (larger in absolute values are more sensitive) and the p-values determine the significance of the sensitivity. A p-value close to zero has more significance. This type of sensitivity can be performed after iteration. The main problem related to global sensitivity analysis is that it needs a large number of simulations (Abbaspour, 2013).

The sensitivity analysis was done for flow and sediment separately since some parameters are sensitive to flow and sediment, some sensitive to flow only and others sensitive to sediment only (Abbaspour et al., 2007).

3.5.2 Model calibration

Model calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions (Arnold et al., 2012).

Calibration can be performed in three ways. These are the manual calibration, automatic calibration and a combination of the two. Manual calibration is tedious, time consuming, and success of it depends on the experience of the modeler and knowledge of the watershed being modeled (Eckhardt & Arnold, 2001). Automatic calibration involves the use of a search algorithm to determine best-fit parameters. It is desirable as it is less subjective and due to extensive search of parameter possibilities can give results better than if done manually.

In Arc SWAT 2012 program the auto calibration tool does not include in the interface to calibrate the model as early version by selecting a simulated model and a sub basin which a discharge outlet located at. Instead, the latter provides option of manual calibration helper to refine the presented parameters for an analysis. Therefore, SUFI 2 in SWAT CUP was used to conduct the calibration procedure. The auto-calibration procedure was supported by manual calibration for the values of parameters that were physically wrong. The values of parameters that are provided by SUFI 2 during calibration as the best parameter value may not be physically correct or it may be outside recommended uncertainty range and needs to be adjusted manually to better match the existing situation. A schematic of SUFI-2 optimization program input file in SWAT CUP is showed in the figure below

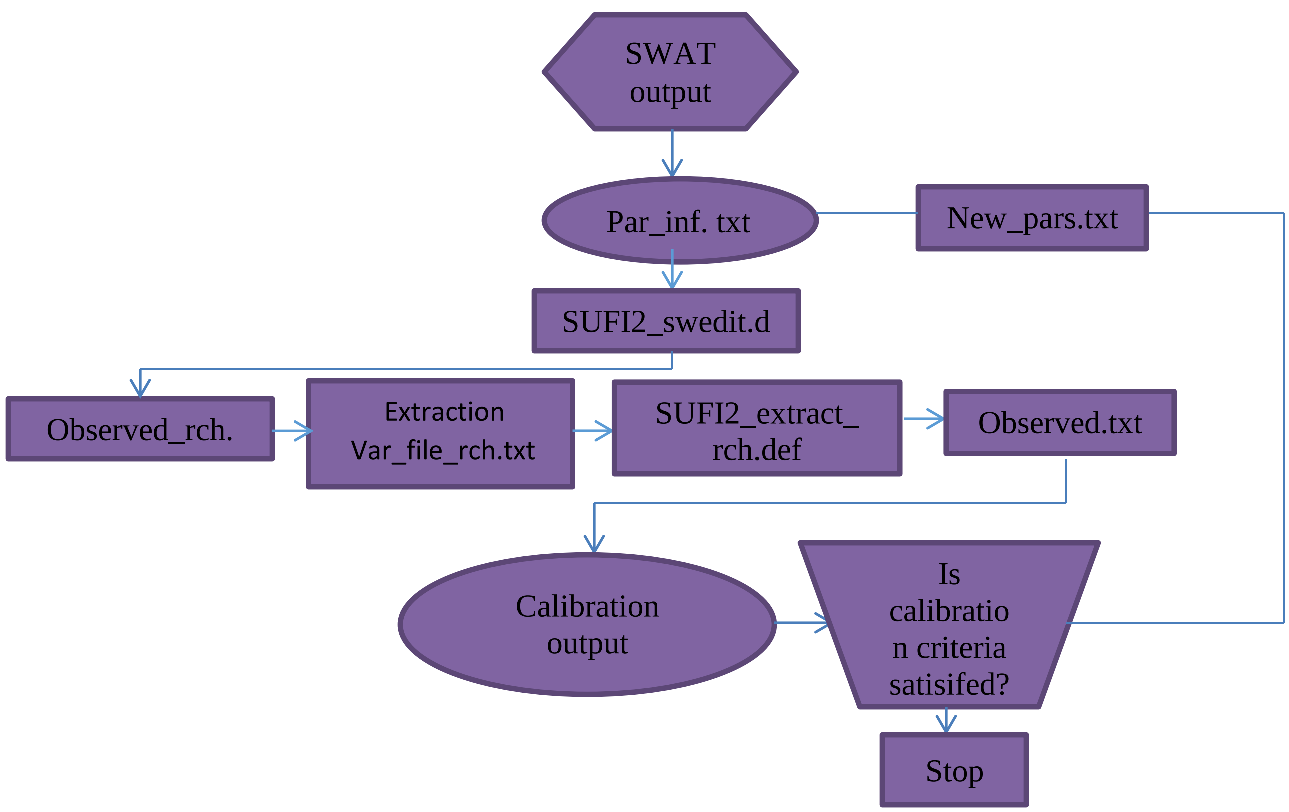


Figure 3.11 step by step creating of SUFI 2 input files (Source: SWAT CUP manual)

After the SWAT CUP program give the acceptable result of the mathematical performance evaluator of the observed and simulated data, the linkage between the swat and optimization program as showed below helps to run the model with the new parameters and satisfy the objective of the study.

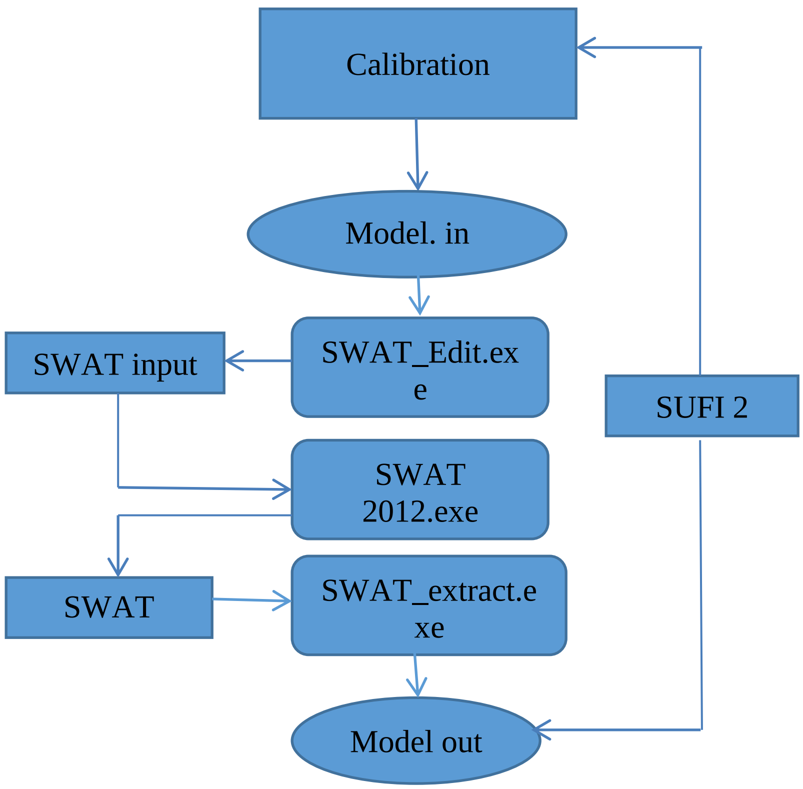


Figure 3.12 Interaction between a calibration program and SWAT in SWAT-CUP

(Source:SWAT CUP manual)

In this study, the parameters used for the calibration process were selected and adjusted using the expert opinion on their literatures. In table 3.6 shows the parameters used for stream flow calibration and table 3.7 parameters used for sediment flow calibration in Katar watershed. As presented in the tables the SWAT default value of the parameter was used for initial calibration purpose.

Table 3.6 List of parameters used in flow sensitivity analysis. (SWAT model)

Parameter Name	Description of parameters	Range of Value
CN2 (..).mgt	SCS runoff curve number	35-98
REVAPMN.gw	Threshold depth of water in shallow aquifer for revap to occur	0-500
ALPHA_BF.gw	Baseflow alpha factor	0-1
ESCO.hru	Soil evaporation compensation factor	0-1
SOL_AWC (..).sol	Available water content of soil	-0.25-0.25
GWQMN.gw	Threshold depth of water in shallow aquifer for return flow to occur	0-5000
GW_REVAP.gw	Ground water revap coefficient	0.02-0.2
HRU_SLP.hru	Average slope steepness	0-0.6
GW_DELAY.gw	Groundwater delay	30-450
SLSUBBSN.hru	Average slope length	10-150
CANMX.hru	Maximum canopy storage	0-10
CH_K2.rte	manning"s "n" Value for the main channel	0-150
SOL_Z (..).sol	Soil depth (for each layer)	-0.2-0.2
SOL_K (..).sol	Saturated hydraulic conductivity (mm/hr)	-0.25-0.25
RCHRG_DP.gw	Deep aquifer percolation fraction	0-1

Table 3.7 List of parameters used in Sediment sensitivity analysis. (SWAT model)

Parameter Name	Description of parameters	Range
SPCON.bsn	Linear re-entrainment parameter for channel sediment routing	0.0001-0.01
CH_COV2.rte	Channel cover factor	-0.001-1
CH_COV1.rte	Channel erodibility factor(cm/h/pa)	-0.05-0.6
SPEXP.bsn	Exponential re-entrainment parameter	1-1.5
RSDIN.hru	Initial Residu cover(kg/ha)	0-1000
USLE_P.mgt	USLE support practice factor	0-1

In this study, the monthly time step calibration process was divided into two steps: first stream flow and followed by Sediment calibration. Calibration was performed until the predicted and observed results were embraced by the model that is $R^2 > 0.6$, NSE > 0.5 and PBIAS <±15 (Santhi et al, 2001).

Flow and sediment calibration for the Katar watershed was conducted from the year 1992-2002 G.C at outlet of sub basin 4 where gauging station is located.

3.5.3 Model validation.

Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate predictions. This implies the application of the calibrated model without changing the parameter values that were set during the calibration, when simulating the response for a period other than the calibration period (Refsgaard, 1997). As the model predictive capability was demonstrated as being reasonable in both the calibration and validation phases, the model was used for future predictions under different management scenarios.

Flow and sediment validation was carried out at a station similar to the calibration. The statistical criteria (the R^2, NSE and PBIAS) used during the calibration procedure were also checked here to make sure that the simulated values is still within the accuracy limits. In this study, the model was validated with independent validation period 2004-2008 G.C for both flow and sediment.

3.6 Model Evaluation

The systematic and dynamic behavior of the model can be visualized by plotting simulated flow and observed flow on the same coordinate system. By looking at the graph a modeler can understand whether the model over predicted or under predicted and also the timing of the rising and falling limb of the hydrograph and give subjective decision on the performance of the model. But, to quantitatively evaluate the model, we need mathematical measures of model performance.

To assess the goodness-of-fit of the model, two methods were used during the calibration and validation periods. These are: coefficient of determination (R^2) and the Nash-Sutcliffe efficiency coefficient (NS). These two statistical parameters are used to measure the model performance.

Coefficient of determination (R^2):-The value of R^2 ranges from (0-1) where a value close to 1.0 indicates good performance (good Co-relation) of the model and the value close to 0.0 indicates poor performance (poor Co-relation) of the model. The main drawback of R^2 is that it only quantifies dispersion. The value of the coefficient of determination is calculated using equation 3.6

$$R^2 \frac{\left[\sum_i \left(Q_{m,i} - \overline{Q_m}\right)\left(Q_{s,j} - \overline{Q_s}\right)\right]^2}{\sum_i \left(Q_{m,j} - \overline{Q_m}\right)^2 \sum_i \left(Q_{s,i} - \overline{Q_s}\right)^2}$$ **……………………..…………...3.6**

Where, $Q\ m$ is the observed (measured) stream flow on day i (m^3/s), $Q\ s$ is the simulated stream flow on day i (m^3/s), and bars indicate averages.

The Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970):- is used to assess the Predictive power of the hydrological models. The value of NS varies from 1.0 (perfect fit) to - ∞. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model (Krause et al., 2005). The NS value of 0.0 indicates that the model predictions are as accurate as the mean of the observed data. According to Krause et al, (2005) the major disadvantage of the Nash-Sutcliffe efficiency is the fact that the differences between the observed and simulated values are calculated as squared values.

This leads to an over estimation of the model performance during peak flows and an under estimation during low flows.

The Nash-Sutcliffe efficiency (NS) is calculated using equation 3.7,

$$NSE = 1 - \frac{\sum_i (Q_m - Q_s)_i^2}{\sum_i (Q_{m,i} - \overline{Q}_m)^2}$$ **…………………………….3.7**

Percent bias (PBIAS): measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is zero, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta et al, 1999) and calculated by equation 3.8

$$PBIAS = \frac{\sum_{i=0}^{n}(Q_{obs} - Q_{sim})}{\sum_{i=0}^{n}(Q_{obs})} * 100$$

……………………………3.8

Where: n is the number of observations during the simulation period, Qobs is the Observed flow data; Qsim, is the simulated flow value with the respected time; and Qobs are the arithmetic means of the observed and simulated values.

The general model performance ratings recommended by *(Moriasi et al, 2007) and (Santhi, et al. 2001)* for monthly time step is given in table 3.8

Table 3.8 Performance Evaluations for Monthly Time Step

Performance rating	R^2	NSE	PBIAS
Very good	0.75< R^2<1.00	0.75< NSE<1.00	PBIAS ≤ ±10
Good	0.65< R^2<0.75	0.65< NSE <0.75	±10 ≤ PBIAS≤ ±15
Satisfactory	0.5< R^2<0.65	0.5< NSE <0.65	±15 ≤ PBIAS≤ ±25
Unsatisfactory	R^2≤0.5	NSE ≤0.5	PBIAS≤ ±25

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Sensitivity analysis

Sensitivity analysis was carried out before calibrating the model to save time during calibration. Identifying sensitive parameters enables us to focus only on those parameters which affect most the model output during calibration since SWAT model has a number of parameters to deal with. Some parameters do not have any influence on the model output while some may have little effect.

4.1.1 Parameters sensitive to flow

Global sensitivity analysis was done using SUFI 2 optimization technique for the parameters shown in table 4.4. These parameters are used to calculate the amount of flow from the watershed. The more sensitive parameter identification was done by using the monthly flow data from 1992 to 2002 G.C with default parameters range. Results of the global sensitivity analysis after the first iteration with 500 simulations rank the sensitive parameters for the Katar watershed as indicated in table 4.1.

Table 4.1. Results of the Global sensitivity analysis after the first initial iteration in SWAT-CUP using SUFI-2

Parameter Name	T-Stat	P-Value	Rank
CN2 (..).mgt	8.68	0	1
REVAPMN.gw	-6.32	0	2
ALPHA_BF.gw	2.29	0.02	3
ESCO.hru	-1.55	0.12	4
SOL_AWC (..).sol	-1.49	0.14	5
GWQMN.gw	-1.25	0.21	6
GW_REVAP.gw	1.23	0.22	7
HRU_SLP.hru	0.85	0.4	8
GW_DELAY.gw	-0.84	0.4	9
SLSUBBSN.hru	-0.76	0.45	10
CANMX.hru	0.54	0.59	11
CH_K2.rte	-0.42	0.68	12
SOL_Z (..).sol	0.33	0.74	13
SOL_K (..).sol	0.27	0.79	14
RCHRG_DP.gw	0.02	0.99	15

The rank for each parameter was assigned depending on P-value and t-stat. Here, P-value indicates the significance of the sensitivity and hence a value close to zero has more significance. On the other hand, t-stat provides a measure of sensitivity and hence larger in absolute values are more sensitive. Parameter will have the same rank whether it is ranked based on the t-stat or P-value.

According to the result from the global sensitivity analysis, the most sensitive parameters are the curve number (CN2) and threshold depth of water in the shallow aquifer for revap to occur (REVAPMN), followed by Ground flow recession factor (ALPHA_BF), Soil Evaporation Compensation coefficient (ESCO), available water content the soil

(SOL_AWC), threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN). The remaining parameters listed on the table have moderate effect on the model output.

The main purpose where sensitivity analysis was carried out before calibrating the model was to save time during calibration by minimizing the parameters that do not have a significant influence on model simulations of measured observations for specific catchments. Thus, the analysis emphasizes the curve number (CN2) will change the result by calibrating this parameter only. But, the majority of the other parameters were also significantly sensitive all the above parameters were used during automatic calibration process in SUFI-2.

4.1.2 Parameters sensitive to sediment

Sensitivity analysis was carried out for sediment to identify parameters that affect sediment yield. Parameters that were used to evaluate the sensitivity to sediment are shown in table 4.5 in chapter four. Among those parameters to see which parameter is highly sensitive to sediment of the study area, the global sensitivity analysis was applied.

The most sensitive parameters for erosion simulations based upon the rank as showed on table 4.2.were: channel re-entrainment linear parameter (SPCON), channel cover factor (CH_COV2), channel erodibility factor (CH_COV1), channel re-entrainment exponent parameter (SPEXP), Initial residue cover (RSDIN) and USLE support practice factor (USLE_P).The sensitivity of the parameter decreases with increasing rank number value and therefore, parameters at the bottom of the table are less sensitive.

Table 4.2. Results of the Global sensitivity analysis after the first initial iteration in SWAT-CUP using SUFI-2

Parameter Name	T-Stat	P-Value	Rank
SPCON.bsn	-12.18	0.00	1
CH_COV2.rte	-7.72	0.00	2
CH_COV1.rte	-7.70	0.00	3
SPEXP.bsn	-2.26	0.02	4
RSDIN.hru	-0.64	0.52	5
USLE_P.mgt	0.37	0.71	6

These sediment parameters are used to compute the amount of sediment from a catchment (from upland) and from the channel (stream sediment), as the sediment transport consists of landscape and channel components.

Therefore, the parameters can be categorized into upland factors which affect the landscape component of the sediment transport and channel factors which affect the channel component of the sediment transport. Parameters such as, USLE _ P and RSDIN, are included in upland factors whereas SPCON, SPEXP, CH _COV1, and CH _COV 2 are categorized under channel factors. As we can see from Table 5.2 the channel factors occupy higher rank in the table that shows stream sediment parameters are very sensitive in this case.

4.2 Model Calibration and Validation

4.2.1 Model calibration and validation for Flow

Model calibration

Before calibration precedes using SUFI-2, the performance of the model was evaluated from the initial simulation run. The initial simulated stream flow results were compared with measured stream flow from the Katar Abura flow gauging station. The comparison was done with the initial year the model simulates for 24 years from 1985-2012 G.C with three year warm-up period (1985-1987) fig 4.1. It can be observed in general that the model under estimated some peaks of measured flow and the base flow. Which means the simulated peak runoff is lower than that of observed value and minimum base flow occurrence.

The NSE was used to judge the initial model performance by using equation 3.7 mentioned in chapters 4.From this the monthly simulation Nash Sutcliffe model efficiency (NSE) of -0.38 were obtained from the initial model run. The result shows the performance indicator was in the unacceptable limits, i.e. NSE < 0.0 (Moriasi et al, 2007). Therefore, the model flow parameters were required adjustment using calibration procedure and this adjustment was based on the sensitivity analysis result of flow parameters.

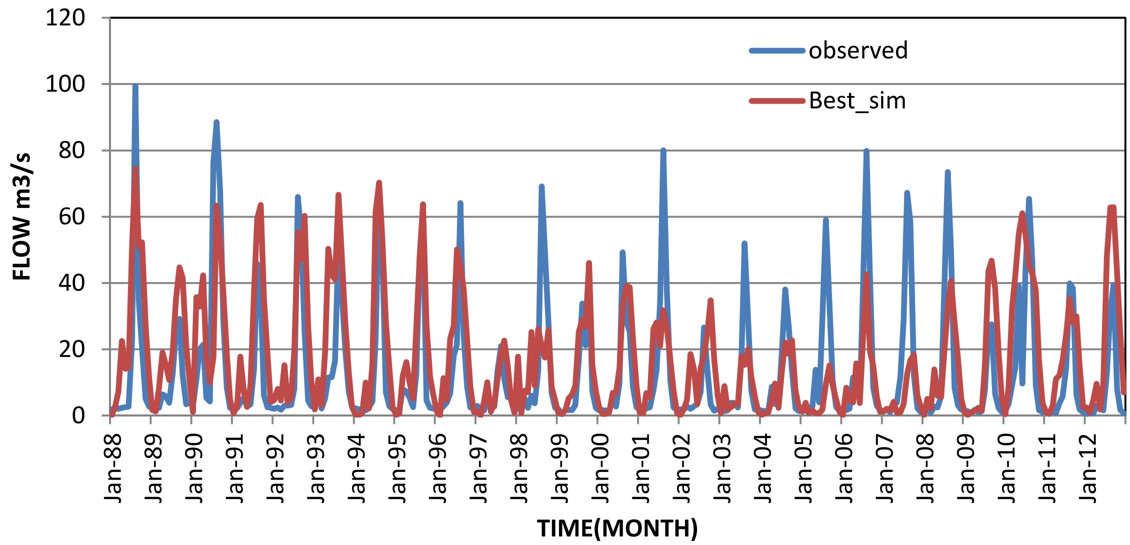


Figure 4.1 Comparison of initial observed and simulated monthly runoff

The calibration of SWAT model for flow was done on the monthly observed stream flow data at the flow gauging station using a time series dataset of 11 years from 1992 to 2002 G.C.Model parameters were calibrated using SUFI 2 optimization program. The calibration processes considered the sensitive parameters and their values were varied iteratively within the allowable ranges until satisfactory agreement between measured and simulated stream flow was obtained. The parameters range that were used in the final iteration in SUFI 2 which gives adequate result of the model performance indicators are shown on the table below. This parameters range also used for validation of the model.

Table 4.3 default parameter range for calibration, calibrated parameter range and final calibrated parameters for flow variable of the watershed.

Parameters	Initial parameter range		Calibrated parameter range		Fitted value
	Min	Max	Min	Max	
V__CN2 (..).mgt	35	98	44.21	45.66	44.97
V__ REVAPMN.gw	0	500	77.72	79.15	78.70
V__ ALPHA_BF.gw	0	1	0.78	0.80	0.79
V__ ESCO.hru	0	1	0.415	0.42	0.419
R__SOL_AWC (..).sol	-0.25	0.25	-0.02	-0.019	-0.0194
V__ GWQMN.gw	0	5000	77.72	79.20	78.73
V__ GW_REVAP.gw	0.02	0.2	0.152	0.154	0.153
V__ HRU_SLP.hru	0	0.6	0.411	0.415	0.414
V__ GW_DELAY.gw	30	450	33.098	33.771	33.532
V__ SLSUBBSN.hru	10	150	12.98	13.19	13.13
V__ CANMX.hru	0	10	0	0.06	0.0001
V__CH_K2.rte	0	150	83.86	84.99	84.101
R__SOL_Z (..).sol	-0.2	0.2	-0.101	-0.0938	-0.099
R__SOL_K (..).sol	-0.25	0.25	-0.030	-0.023	-0.029
V_RCHRG_DP.gw	0	1	0.0160	0.0183	0.0175

* Relative (R__) means the existing parameter value is multiplied by (1+a given value).
Replace (V__) means the existing parameter value is to be replaced by the given value.

After the water-balance was calibrated, the final set of parameters obtained from the calibration process was then entered into the Katar watershed SWAT model and the final simulation was run. And the results were evaluated by comparing the modeled results with the measured stream flow at Kata Abura gauging station.

In Table 4.4, the catchment stream flow indicates an acceptable agreement between the measured and simulated monthly flows as indicated by the value of the model performance indicators as per (*Moriasi et al, 2007*) in table 3.5.

The results found to be Coefficient of determination (R^2) of 0.8, Nash–Sutcliffe efficiency (ENS) of 0.77, and Percent bias -6.63. The result also indicated that model was calibrated satisfactorily to simulate monthly stream flows adequately. The calibration result demonstrates SWAT‟s ability to predict realistic flow.

Table 4.4 Monthly average monthly flow statistics for calibration of the Katar River Catchment

Calibration period	**Mean monthly flow m^3/s**		**R^2**	**ENS**	**PBIAS**
	Observed	Simulated			
(1992-2002)	12.45267176	13.2788229	0.8	0.77	-6.634

During the calibration period, the simulated monthly flows matched well with the measured monthly flows as shown in Figures 4.2 and 4.3. The trends of seasonal variability and monthly average discharge were generally well captured. However, the model slightly under estimates the peak monthly flow in most of the simulation periods. Some stream flow events are still not completely represented by the calibrated modeled. This may be due to the climate gauges has high missing data (which left the value -99.0) of within the watershed used as model input. *(Lemma T, 2015 and Nina K.,2016)*

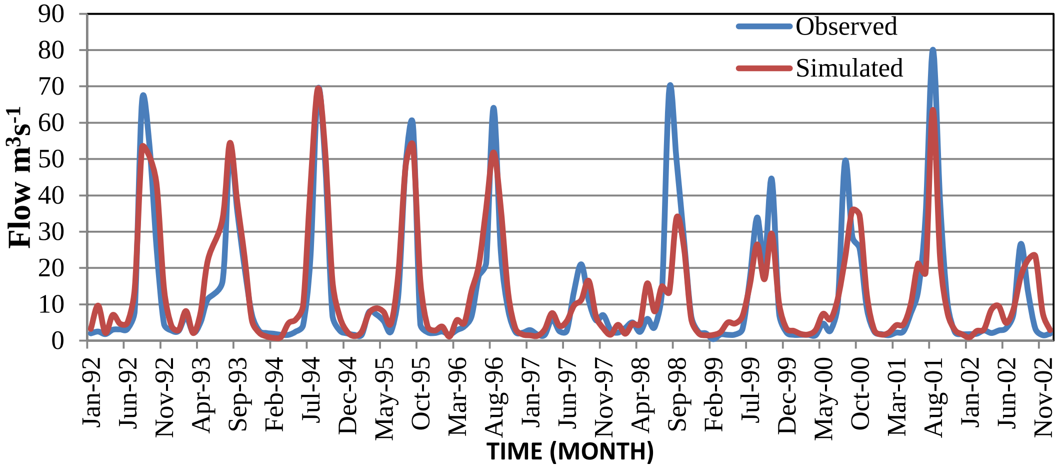


Figure 4.2 Calibration of observed and simulated monthly flow hydrograph, for a period (1992-2002).

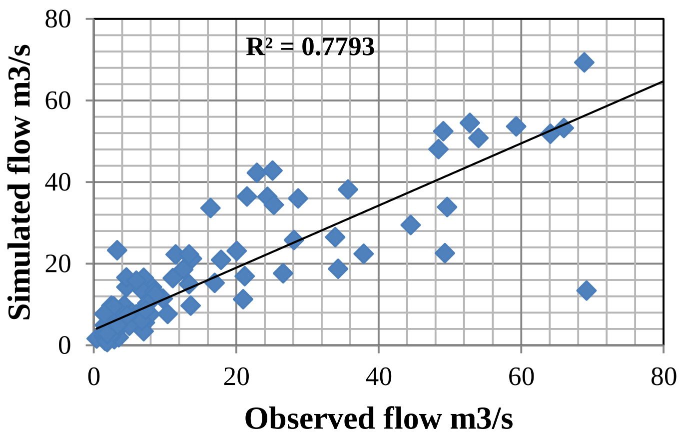


Figure 4.3 Scatter plot of observed and simulated discharge, for a period of (1992-2002)

Model validation

Validation of the model was done for an independent data set of five years from 2004 to 2008 G.C. Accordingly, good match between monthly measured and simulated flows in the validation period were demonstrated by the correlation coefficient (R^2) of 0.78, Nash-Sutcliffe simulation efficiency (ENS) of 0.75 and Percent bias 5.33 of measured and simulated flows for the monthly flow was found (Table 4.5).

Table 4.5 Monthly average monthly flow statistics for validation of the Katar River Catchment

Validation period	Mean monthly flow m^3/s		R^2	ENS	PBIAS
	Observed	Simulated			
(2004-2008)	14.4816667	13.7100667	0.78	0.75	5.3

The hydrograph of the validation period of the observed and simulated flow in monthly estimation indicated that the model slightly under estimates some of the peak flows of the months and most of the month's base flows were over estimated by the model (Figure 4.4).

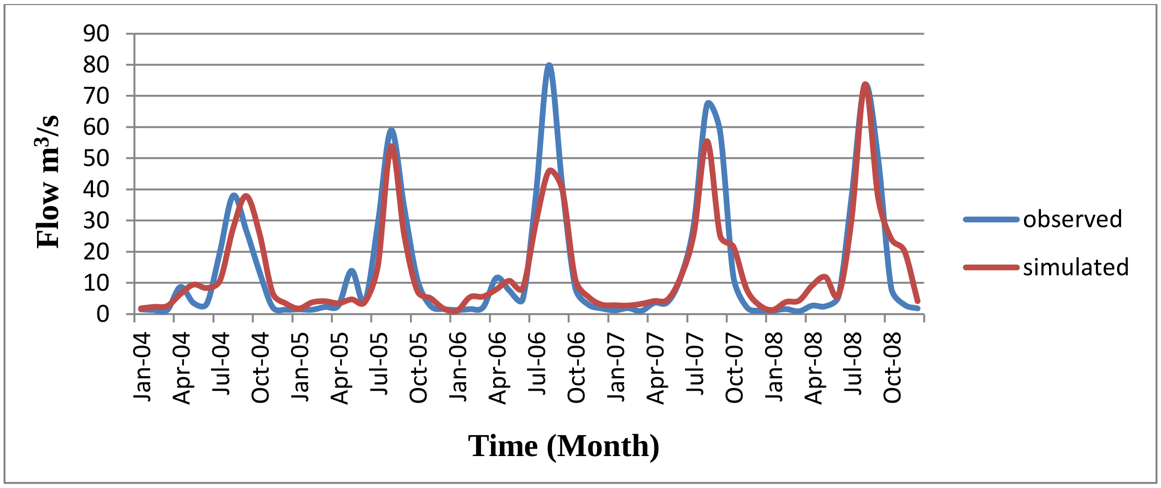


Figure 4.4 Validation of observed and simulated monthly flow hydrograph, for a period (2004-2008).

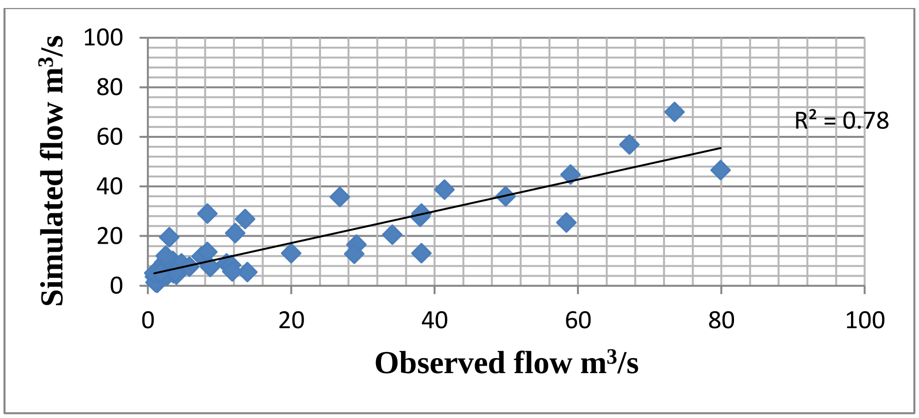


Figure 4.5 Scatter plot of observed and simulated discharge validation, for a period of (2004-2008).

4.3 Model calibration and validation for sediment

Sediment yield calibration

Once it is shown that the flow was accurately represented by the model the emphasis is moved to the calibration of the model for sediments. Sensitivity analysis was carried out for sediment to identify parameters that affect sediment yield by SUFI 2 which indicated in table 4.2.

Once the sensitive sediment parameter identified in the first iteration, the calibration of the model was done using SUFI 2 in SWAT-CUP for 11 years from 1992-2002G.C based on the parameters result which has effect on the simulated sediment yield of the watershed when varying iteratively within the allowable ranges of the parameters.

Table 4.6 Default and final calibrated Sediment Parameter values of the watershed

Parameters	**Initial parameter range**		**Calibrated parameter range**		**Fitted value**
	Min	Max	Min	Max	
V__ SPCON.bsn	0.0001	0.01	0.00452	0.00498	0.00476
V__CH_COV2.rte	-0.001	1	0.34	0.41	0.37
V__CH_COV1.rte	-0.05	0.6	0.14	0.18	0.16
V__ SPEXP.bsn	1	1.5	1.05	1.11	1.06
V__ RSDIN.hru	0	1000	401.01	555	492
V__ USLE_P.mgt	0	1	0.35	0.45	0.36

Once the sediment parameter fitted values are established, the SWAT model for sediment simulation is run again with the calibrated parameters. The observed and the simulated values of the sediment yield were plotted against each other to determine the goodness-of-fit criterion of coefficient of determination (figure 4.6). The coefficient of determination (R^2),the Nash-Sutcliffe efficiency and percent of bias were found to be

0.75,0.73 and -10 respectively. The range of model performance indicators are within the acceptable value as per the *Moriasi et al, 2007 and* Santhi, et al. 2001.

Calibration results show that model performance is good with simulation of monthly sediment load.

Table 4.7 Calibration statistics of monthly observed and simulated sediment load

Calibration period	Mean monthly sediment in ton		R^2	ENS	PBIAS
	Observed	Simulated			
(1992-2002)	85805.56	94381.97	0.75	0.73	-10

The hydrograph of the calibration period of the observed and simulated sediment load in monthly basis shows the model slightly under-estimated some of monthly sediment yields of the watershed of July of 1992, July 1998 and July 2001. (Figure 5.7).SWAT uses the simulated runoff to determine the sediment yield from the watershed, the model under predicted the sediment yield where the simulated runoff from the same watershed is less than the observed runoff. *(Lemma Tufa Bokan,2015)*

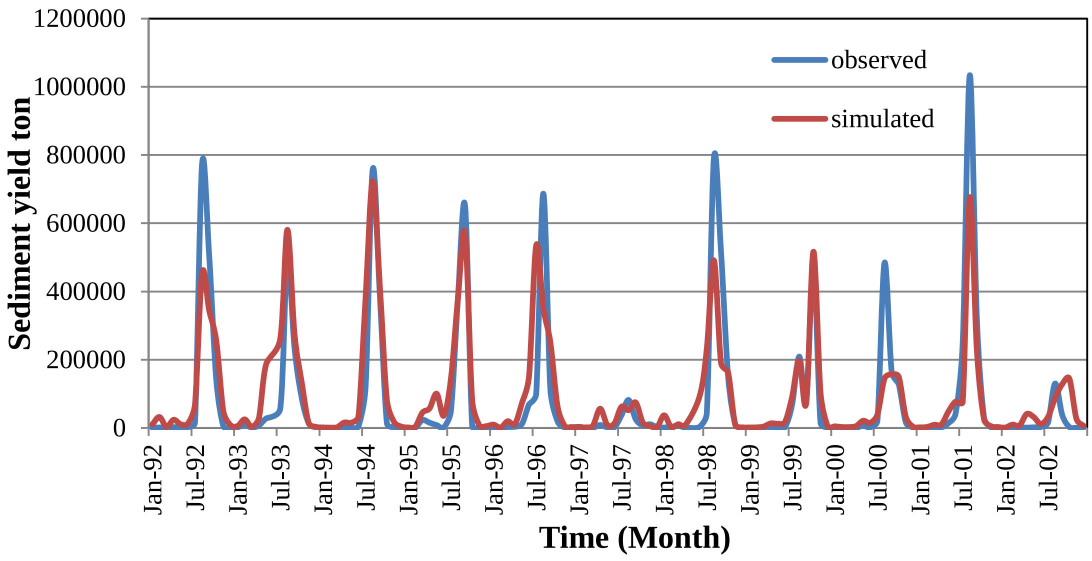


Figure 4.6 Calibration of observed and simulated monthly sediment yield hydrograph, for a period (1992-2002).

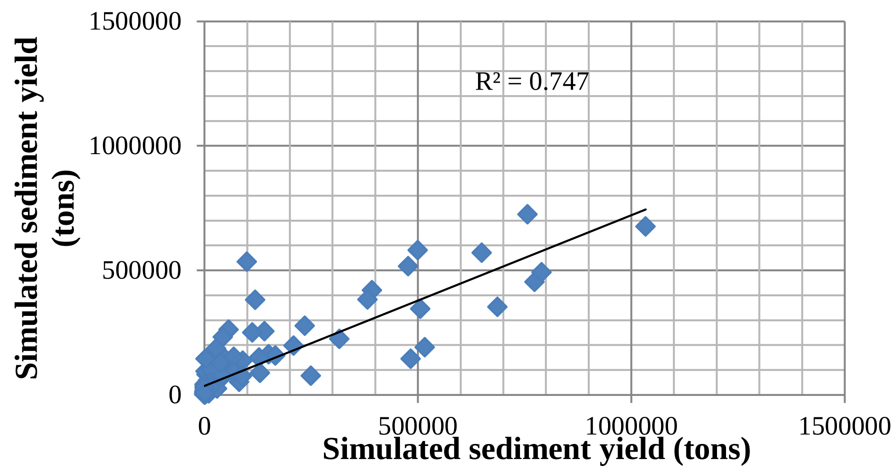


Figure 4.7 Regression analysis line of simulated versus observed monthly sediment yield for calibration period (1992-2002)

Sediment Yield Validation

After calibration, then SWAT model was validated to sediment for the period 2004 to 2008 using the same parameters, which were adjusted during calibration processes. Monthly model simulated sediment load against monthly measured sediment load were compared graphically and statistically.

As indicated in the model's performance statistics (Table 4.8); R^2, NSE and PBIAS were found to be 0.65, 0.64 and 3.3 for validation period respectively which shows good agreement between observed and simulated sediment load.*(Tensay G,2011)*

Table 4.8 validation statistics of monthly observed and simulated sediment load

Validation period	Mean monthly flow m^3/s		R^2	ENS	PBIAS
	Observed	Simulated			
(2004-2008)	97650.69	94424.71667	0.65	0.64	3.3

The observed and simulated sediment yield in monthly time step of the validation period shows that model slightly under estimate the sediment yields of time periods in year 2007 and in specific months over estimation Sep-08 (Figure 4.8).

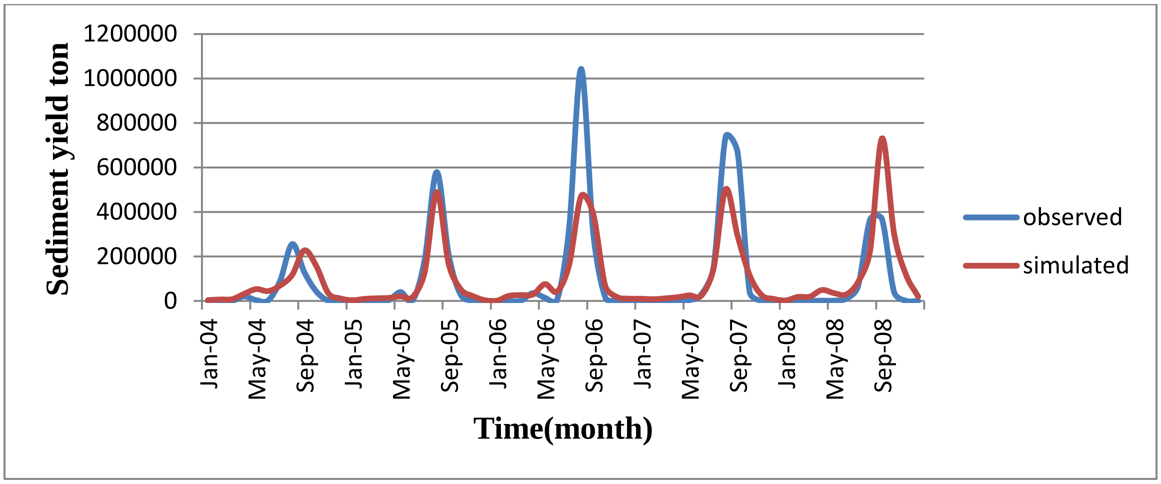


Figure 4.8 validation of observed and simulated monthly sediment yield hydrograph, for a period (2004-2008).

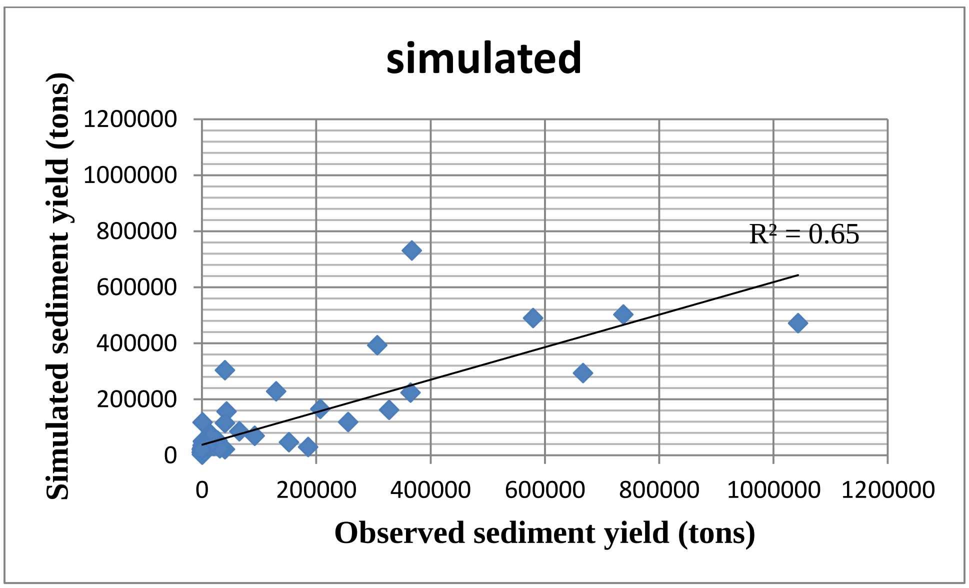


Figure 4.9 Regression analysis line of simulated versus observed monthly sediment yield for validation period (2004-2008).

4.4 Spatial distribution of sediment yield in Katar watershed

Identifying erosion prone areas in the watershed enables the watershed management to be applied to the proper areas to reduce the sediment yield. Spatial analysis of sediment prone areas is one of the many tasks SWAT can do while modeling sediment. SWAT is powerful in spatial visualization of sub basin or HRU level detail so that one can see which area produces high sediment and which area produces less. After Calibration and validation, the model was run for a period 28 years from 1988 to 2015G.C. From the model simulation output, sediment source areas were identified in the Katar Watershed.

The spatial visualization of sub basin wide sediment yield in tons/ha is given in Figure 4.10 below.The simulated annual average sediment yield by SWAT model was 2.1t/ha/yr. (See Appendix V). A study of soil formation rates and tolerable soil loss level for different Agro-ecological zones of Ethiopia were 2-18 t $ha^{-1}yr^{-1}$. Based on the study area situation the annual sediment yield of the map was reclassified into three major categories of soil erosion hazards region i.e. low, moderate, and severe erosion conditions as shown on the table below.

***Table 4.9 Sub basin areas and sediment yield* (** (Hurni, 1983)

class	Sediment yield ton/ha	Category of soil erosion region
1	0.001-7 t/ha/year	low
2	7-18 t/ha/year	moderate
3	18-46.86	sever

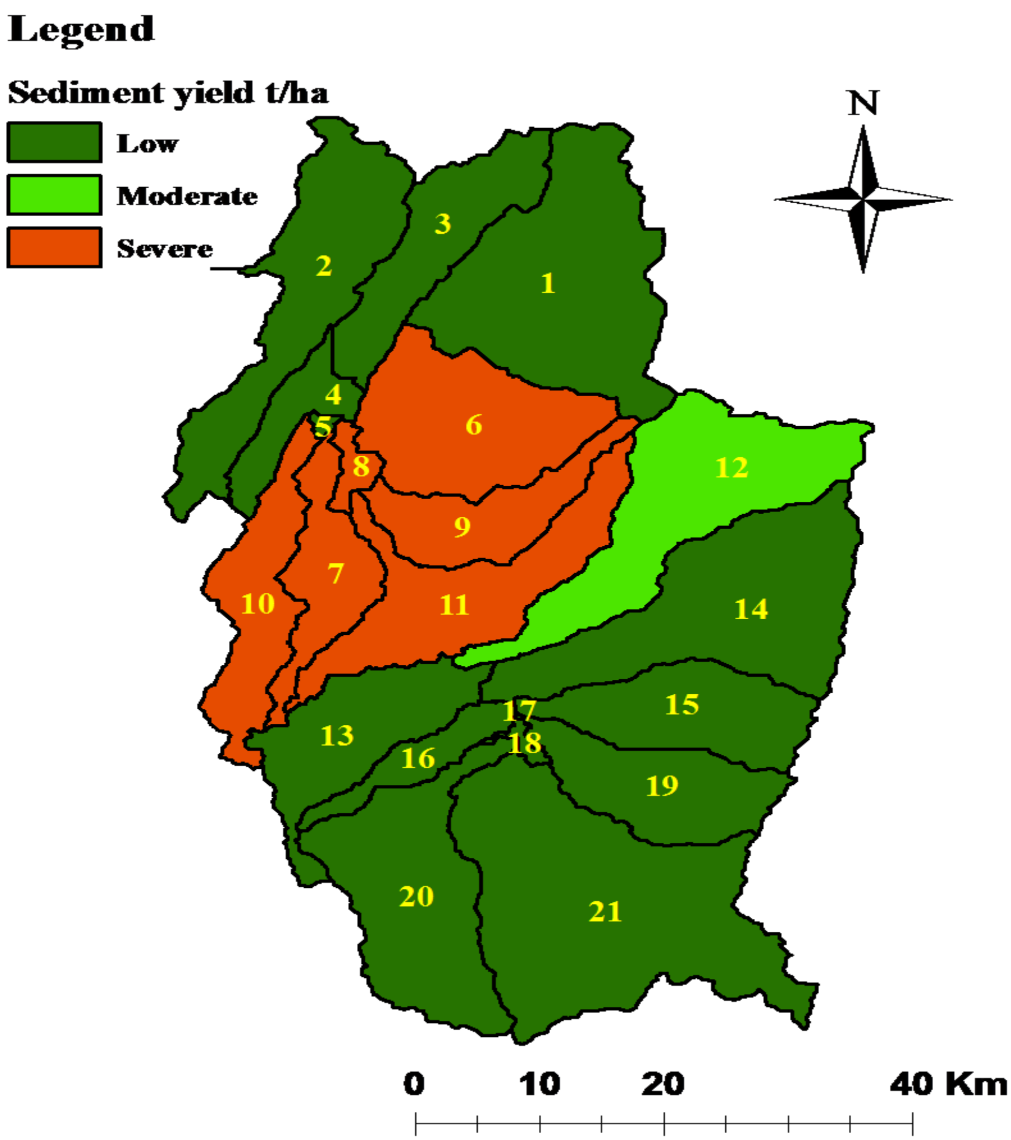


Figure 4.10 Spatial visualization of sediment output from SWAT model

In the map Sub-basins 6, 7, 8, 9, 10, and 11 produced the highest sediment yield and more exposed for erosion. These watersheds are located in agricultural land and with soil property of Pellic Vertisoil. As discussed in the above chapters, Katar water shade is experienced land use and land cover change from year to year.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Land degradation is becoming a major issue in the world particularly in the developing countries. Ethiopia being a developing and agricultural country it is very important to study the causes of land degradation and design controlling mechanisms to this risk. In most parts of Ethiopia, land degradation is manifested in the form of soil erosion. The study area, Katar catchment, is one of highly arable lands in the country susceptible for high soil erosion.

In this study, a physical, semi-distributed parameter, continuous time, river basin model, SWAT 2012 was used to simulate runoff and sediment from Katar watershed of Rift Valley River Basin. The model operates on a monthly time step and allows a catchment to be subdivided into sub-catchments. The main objective of this thesis is to predict the amount of Sediment Yield from Katar watershed. In addition to this, to assess and evaluate the spatial variability of sediment yield and identify vulnerable sub-watersheds for erosion and sediment yield in the watershed. A GIS interface was used to prepare and process a geospatial data required running the model. Model parameters were derived, spatial data including elevation (DEM) obtained from WWDSE. The watershed parameters were derived from DEM resulting in 21-subbasins and sub basins were further broken down in to hydrological response units based on the land use, soil and slope. This resulted in 156 HRU’s.

Automatic calibration and validation of SWAT model using Sequential Uncertainty Fitting version two (SUFI 2) was conducted. The model was calibrated and validated by using eleven years (1992 to 2002) and five years (2004-2008) for stream flow and with similar year the sediment was also calibrated and validation using the rating curve equation which generated from measure data of two years (1992 and 2005) collected from Ethiopian water, irrigation and electricity minister (MOWIE) at the katar river Abura gauging station.

The average simulated monthly flow and sediment yield by SWAT were compared with the corresponding average values of the observation using graphical and statistical methods. As it is seen from the model performance efficiency indicators result, coefficient of determination (R^2) and the Nash-Sutcliffe (ENS) are found to be 0.8 and 0.77 in calibration and 0.78 and 0.75 in validation for flow analysis. Similarly, sediment model efficiency indicators R^2 and ENS 0.75 and 0.73 for calibration and 0.65 and 0.64 in validation respectively.

Based upon, the acceptable limit of the statistical model evaluation criteria; Calibration and validation of the SWAT model show that the simulated daily stream flow and sediment yields a good much with measured values. Therefore, the study demonstrated that the river basin scale model, SWAT has the capability of simulating runoff and sediment from Katar watershed.

The twenty eight years sediment yield simulation result indicates that the simulated annual average sediment yield by SWAT model was 2.1ton/ha/yr (210 ton/km^2/year). The result shows annual soil loss rate in the study area is in tolerable condition.

When we compare this study with other studies conducted in this area, the mean annual sediment yield were estimated by WWDSE using regional sediment rating curve of

$Q_s = 16.205Q^{1.399}$ with $R^2 = 0.971$

Where: Q_s = Suspended sediment mass transport rate (ton/day) , Q = discharge (m^3/s)

Based on the above rating equation the annual suspended sediment yields estimated for the period of 1969-2004 G.C were 128 ton/km^2/year. In this study SWAT model estimate 1.6 times greater than the WWDSE estimates. This is because, as indicated in the research conducted by Damtew (2010) of the study area experienced a great land use and land cover change for the last three decades and agricultural land was increased by 27.7% between 1986 and 2010, with annual rate of (15.5 km^2/year).

On the basis of the results obtained in this study, the SWAT model performed well in predicting both the flow and sediment yields from the Katar watershed and the results were acceptable. The result of this study could have been better if spatially distributed precipitation data, long period of runoff and sediment yield data had practical.

5.2. Recommendation

This study can be considered as a preliminary work for further research work and for different stakeholders to plan and implement appropriate soil and water conservation strategies in the watershed.

The following points are recommended

- SWAT model calibrated using observed flow data at gauging station and the model prediction output also depend on this calibrated parameters. Therefore, in order to improve the model performance, the weather stations should be improved both in quality and quantity.
- The sediment data used for this study were generated from sediment rating curves developed from limited sediment measurement data. Consequently, there will be possible discrepancy of actual sediment and sediment data derived based on rating curves.

However, superior results can be obtained if intensive sediment measurements (low and high flows of Katar at Abura gauging station). Hence, responsible bodies should give due attention to the time and frequency of sampling, method of sampling and recording of reliable sediment data together with flow measurement.

- A comparison of similar basin characteristics with the study area are required to validate the current estimates of sediment yields.
- Creating awareness among farmers about short-term and long-term impacts of land degradation and designing appropriate strategies that participate farmers in soil and water conservations.
- Providing the farmers with agricultural intensifying inputs so that they can get sufficient amount of production from their farm land, this would avoid their need for additional land.
- Expansion of non-farm employment and alternative income generating strategies for the farmers to decrease the need for additional farm land which also decreases farming on marginal lands
- Further study is required in different scenarios to decide a type of coverage and extent of application on different sub basins. And also the high sediment yielding areas should be verified by field measurements.

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Appendix I

Precipitation data used for this specific study

ARATA													
No	Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1985	5.7	2.6	51.1	98	60	46.2	157.3	100.7	106.2	26	6.4	0.2
2	1986	0	55.2	79.1	112.9	99.5	133	189.1	86.4	182	29.3	10.8	3.8
3	1987	0	-99	-99	74.7	180.7	52.8	81.5	104.2	58.5	9.3	0	5
4	1988	4.5	29.5	2.3	78.9	33.9	159.8	133.2	134.1	109.4	31.4	0	0
5	1989	1.9	21.3	54.4	91	12.4	89.3	-99	146.3	89.2	16.3	0	9.6
6	1990	0	131.2	42.3	55.7	41	51.1	154.9	131.6	128.1	5.7	5	0.4
7	1991	1.4	35.6	176.9	12.5	58.4	97.1	-99	71.9	107.4	-99	3.7	34.5
8	1992	69.3	72	34.7	81.1	42.6	62.2	131.6	-99	-99	-99	-99	6.4
9	1993	25.4	20.3	19.5	102	134.4	52	216.9	119.9	91.6	53.6	2.8	3.3
10	1994	0	0	37	17.7	56.4	177.6	120.9	98.8	120	0.2	9.3	0.1
11	1995	0	40.6	182.2	221.6	55.9		94.5	137.4	113.7	16.5	0	16.5
12	1996	26.6	0	77.7	48.1	152.3	234.8	122.7	129.3	113.7	14.6	2.6	0
13	1997	0.7	5.7	109.5	183.9	60.7	91.1	153.4	57.8	80.7	108	31.1	0
14	1998	56.2	63.6	83.8	53	66.4	106	111.2	126.2	140	105.9	16	0
15	1999	-99	-99	46.1	12.8	24.7	98.2	115.1	67	73.5	213.5	17.8	0
16	2000	0	0	2.7	89	115.4	79.1	152.1	127.1	143	18.4	78.4	0
17	2001	0	28.4	110.6	20.3	127.8	128.1	67.1	189.3	163.9	1.5	0	0
18	2002	3.2	74.5	85.6	29.7	89.6	38.8	46.2	136.1	49.7	1.3	0	20.5
19	2003	0	51	39.5	107.5	58.6	121.6	150.1	79.1	107.6	7.1	20.4	28.7
20	2004	12.1	3.2	28.1	91.4	13.9	73	102.1	65.7	149.4	62.3	0	1
21	2005	53	6.5	46.9	121.1	136.4	77	111.2	88.8	109.2	16.1	19.2	0
22	2006	4.5	17.2	64.7	130	20.1	119.4	155.5	113	83.6	12.7	0	3.2
23	2007	11.7	10.2	36.1	72.6	122.7	129.8	178.6	117.4	87.1	21.3	4.3	0
24	2008	1.6	0	0	36	96	112.2	230.6	154.8	82.9	59.3	75.5	0
25	2009	32.8	2.4	72.6	52.2	46.8	44.6	102.2	-99	-99	-99	-99	-99
26	2010	0	83.8	90.1	120.8	154.2	95.1	210.1	90.9	103.9	7.2	0.8	4.5
27	2011	0.9	18.7	-99	45.3	-99	82.1	152.8	155.7	88.3	0	24.4	-99
28	2012	0	0	12.3	72.6	30.7		221.5	184.2	163.8	7.5	0	-99
29	2013	17.8	0	122.1	16.5	96.2	61.4	193.3	104.4	70.6	105.8	0.8	0
30	2014	0	7.5	76.7	43.1	77.7	32.5	175		165.3	103	15.8	0
31	2015	0	0	-99	9.3	63.5	134.9	87.8	51.2	79.7	0	0.5	-99

BEKOJI													
No	Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1985	24.1	1.6	98.1	137.6	175.1	109.4	211.4	143.3	38.4	54.7	4.9	2
2	1986	5	65.9	47.6	142	110.9	209.4	136.7	234.8	63	48.3	7.8	7.5
3	1987	2.5	43.9	203.6	120	125.5	96.6	75.1	169.4	63.5	40.6	3.2	30.2
4	1988	5.9	36.5	85	202.6	56.4	90.5	177.3	-99	102.5	129.2	8.3	5
5	1989	20.2	46.2	98.3	157.6	80.8	87.1	172.9	161.3	60.9	101.1	11.6	83.7
6	1990	0.4	224.9	113.3	141.7	38.9	68	-99	217	76.9	4.4	17.2	3.3
7	1991	5.3	68.5	141.6	30.2	81.1	130.4	194.7	-99	91.1	8.9	0.9	30.2
8	1992	112.9	91.2	40	132.7	51.5	124.4	158	219.8	31.1	126.7	52.4	13.1
9	1993	63.2	91.4	2	159	172.1	128.5	167	212.2	134.3	49.8	3.5	3.2
10	1994	0.8	0	37.6	128.7	49.8	173.2	243	273.7	94.7	6.8	38.1	5
11	1995	0	41.6	94	152	73.7	49.6	199.5	230.6	140.2	16.1	1.2	33
12	1996	58.1	12.3	140.2	55.5	156.1	-99	225.7	160.7	83.7	35	3.1	-99
13	1997	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
14	1998	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
15	1999	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
16	2000	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
17	2001	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
18	2002	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
19	2003	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
20	2004	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
21	2005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
22	2006	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
23	2007	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
24	2008	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
25	2009	-99	-99	-99	-99	-99	61.6	161.2	256.8	92.9	-99	-99	-99
26	2010	1.5	130.5	185.1	-99	-99	-99	-99	-99	-99	-99	-99	-99
27	2011	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
28	2012	-99	-99	-99	-99	34	154.5	-99	-99	-99	-99	-99	-99
29	2013	8.3	0	85.9	124.9	64.6	-99	-99	177.3	63.5	77.8	-99	-99
30	2014	-99	-99	-99	-99	155	118	291.8	259.8	116.5	124.5	-99	-99
31	2015	0	0	51.3	64.5	103.5	147.5	-99	-99	-99	-99	-99	-99

KETERA													
No	Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1985	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
2	1986	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
3	1987	-99	-99	-99	182	194.6	38.8	57	101.7	49.3	15.4	0	0.1
4	1988	2.4	56.6	25.8	105.3	85.2	122.8	238.4	131.5	110.7	30.7	0	0
5	1989	3.3	14.1	84.9	99.1	23.5	79.2	115.8	144.8	207.9	21.9	0	3
6	1990	2.3	98.7	39.7	54.6	46.1	46.2	170.8	281.2	140	30.5	0	0
7	1991	9.3	44.9	103	55.5	16.5	101.1	226.8	107.8	89.8	32.9	0.6	7
8	1992	17.6	7.3	0.5	9.2	67.2	92.6	85.2	203.8	130.9	124	1.5	4.1
9	1993	15	40.5	1.7	115	209.2	74.7	77.4	106.4	38.5	27.2	0	0
10	1994	0	0	11.2	84.5	66.3	173.5	175.5	57.8	87.9	0.5	11.2	0.4
11	1995	0	15.6	92.1	89.9	62	63.7	130.1	110.9	78.3	19.2	0	42
12	1996	2.4	0	76.9	70.1	77	147.5	133.3	134	87.7	0	0	0
13	1997	5.1	0	71.1	107.7	56	115.9	123.1	73.8	59.5	37.5	10.5	0
14	1998	94.5	25.5	-99	-99	141.2	143.1	73.8	110.8	109.2	96.8	2.5	-99
15	1999	-99	-99	32.8	22.1	88	114.5	124.8	114.4	94.2	147.6	0	0.1
16	2000	0	0	14.3	73.9	87.8	149.4	131.6	202.1	184.2	56.4	33.4	0
17	2001	0	19.5	75.5	54.3	217.2	135.5	127.9	76.2	71.8	10.5	0	0
18	2002	3.7	4.1	93.9	15.3	130.9	46.1	95.8	95.8	45.9	0	0	14.4
19	2003	1.1	5.6	10	31.9	93.9	77.2	205	58.5	122.1	0	0	5.2
20	2004	-99	-99	-99	-99	30.3	38.5	-99	163.4	101.9	63	0	0
21	2005	19.6	0	0	-99	-99	30.6	49.3	50.7	-99	-99	-99	-99
22	2006	-99	-99	-99	24.7	67.2	108.1	206.7	117.6	95.6	40.2	0	6.3
23	2007	32.6	10.2	45.8	-99	-99	-99	125.6	106.9	-99	-99	0	-99
24	2008	-99	-99	-99	111.9	109.3	117.3	143.7	166.4	99.4	15.6	57.7	-99
25	2009	-99	-99	30.3	53	54.3	-99	-99	154.2	86.2	83.5	0	0
26	2010	0	47.7	114.7	190.7	244.7	164	180.3	183.9	96.8	51.3	-99	-99
27	2011	0	13.8	46.5	-99	-99	-99	144.3	-99	-99	-99	-99	-99
28	2012	-99	-99	-99	97.4	0	166.5	213.3	294.6	118.6	6.3	5.3	10.1
29	2013	0	-99	-99	0	-99	90.7	-99	375.2	171.5	43.6	-99	-99
30	2014	-99	-99	-99	29.9	131.6	-99	-99	-99	-99	-99	-99	-99
31	2015	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99

KULUMSA													
No	YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1985	8.6	8.8	15.3	84.7	56.5	60.8	130.1	95.8	108	25.5	1.2	1
2	1986	1.8	154.7	87.3	120.7	87.9	108.8	108.2	76.6	120.2	43.9	11.7	16.2
3	1987	2.2	26.2	118	136.8	159	48.9	63.7	111.9	88.2	5.8	3.1	11.7
4	1988	64.2	79.3	25	114.6	61.7	80.4	133.9	127.7	131.2	56.3	0	0.1
5	1989	0.2	50.4	70.5	177.3	25	132.4	125.9	174.4	83	31	5	41.2
6	1990	0	166.5	109.5	140.4	35.1	106.4	172.3	104.4	123.7	19.3	5.5	2.9
7	1991	8.4	42.7	185.3	11.1	93.1	68.3	158.7	125	78.8	10.8	0	12.1
8	1992	38.9	83.6	4.7	65.4	33.1	78.5	103.5	175.3	94.4	81.5	36.1	14.5
9	1993	20.7	71.8	12.9	148	163.4	44.2	115.9	135.7	129.3	57.9	0	30.8
10	1994	0	13	34.5	68.4	41.1	163.9	118.1	137.2	101.4	1.1	32.9	15.4
11	1995	0	34.1	168.2	136.1	67.6	78.2	119	147.2	68.5	2.2	0	45.8
12	1996	42	4.3	133.3	58.9	186.9	130.2	133.7	104.9	79.2	0.1	3.5	0
13	1997	6.4	0	218.2	112.7	35.3	115.7	146	98.2	59.9	93.5	25.7	0
14	1998	27.8	-99	51.4	69.1	94.3	81.8	103.9	183.4	96.8	106.1	35	0
15	1999	5.4	3.3	70.8	26.2	78.2	91.1	105.8	123.3	82.6	159.9	0	0
16	2000	0	0	1.7	76.4	143.5	168.1	141.6	94.2	108.7	34.4	27.3	1.6
17	2001	0.5	22.4	186.1	12.2	196.3	154.5	96.7	172.2	80.9	10.9	6.2	0
18	2002	102.9	68.4	50	70.8	61.6	56	44.6	168.4	46.1	1.6	0	38
19	2003	16.2	42.6	94.2	128.1	21.6	114.6	123.4	96.2	100.3	0	0	21.4
20	2004	56	1.5	25.6	94.1	15.5	103.7	104	96.9	156.1	70.9	0.9	2.8
21	2005	48.3	45.1	108.7	128.8	69.5	63.7	67.8	81.4	85.1	18.8	25.8	0.3
22	2006	5	16	87.2	126.9	62.2	80.3	161.8	104.8	76	77	2	6.5
23	2007	27.2	59.6	49.4	89.9	163.9	113.5	134	98.3	77.5	16	6.6	0
24	2008	0.5	2.3	1.4	40.3	85.1	-99	192.1	200.4	100.6	90.6	53.9	0
25	2009	20.3	10.8	35.5	50.2	61.7	57.5	171.6	205.3	79	68.3	0.9	26.8
26	2010	4.5	127.4	101.1	107.2	94.7	115.9	147.6	91	118.1	3.3	3.5	3.5
27	2011	8.4	25.6	133.3	74.8	104	65.2	113.9	153.7	166.8	0	4	0
28	2012	1.4	2.5	28.9	100.7	72.7	76	205	180.8	272.1	3.8	4	13.3
29	2013	7.5	0	95.3	31.1	127.5	52	203.1	77.5	113.5	36	6.3	0
30	2014	0	29.7	76.3	65	110.2	40.8	49.3	119.5	158.7	214.7	1.5	-99
31	2015	-99	-99	0	17.9	156.2	122	60	75.1	110.7	12.7	-99	-99

MERARO													
No	Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1985	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
2	1986	32.3	89.6	81	269.1	196.7	245.7	253.3	218.6	129.4	74.6	34.7	53
3	1987	4.2	94.6	237.6	138.7	238.9	32.9	133.8	215.1	94.2	-99	-99	-99
4	1988	-99	-99	-99	130.8	-99	59.5	-99	-99	-99	-99	-99	-99
5	1989	-99	22	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
6	1990	201.2	-99	94.9	-99	-99	-99	122.5	112.1	-99	3.8	-99	-99
7	1991	-99	-99	138.5	-99	-99	-99	-99	-99	-99	3.3	0	4.4
8	1992	43.4	15.2	7.1	60.4	-99	77.6	117.7	-99	67.2	-99	-99	-99
9	1993	-99	-99	-99	-99	-99	-99	119.4	191.4	-99	52.8	3.4	0
10	1994	-99	0	34.5	-99	-99	-99	-99	-99	-99	-99	-99	-99
11	1995	0	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	13.3
12	1996	52.3	5.1	-99	45.4	89.9	-99	-99	-99	-99	-99	-99	-99
13	1997	-99	0	34.5	-99	-99	-99	-99	-99	-99	-99	-99	-99
14	1998	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	0
15	1999	16.3	7.8	129	16	52.2	-99	-99	-99	-99	-99	1.4	0
16	2000	3.2	0	0	69.7	20.9	69.4	-99	162.6	-99	-99	-99	-99
17	2001	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
18	2002	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
19	2003	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
20	2004	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
21	2005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	54.5
22	2006	44.3	117.1	-99	-99	-99	171.3	121.4	42.1	-99	15.2	-99	-99
23	2007	37.4	124.6	33.8	72	165.6	190.4	214.2	40	16.6	0	1.5	5.7
24	2008	0.6	27.6	37	97.4	140.9	149.2	72	34.5	130.4	2.1	14.5	-99
25	2009	-99	48.6	31.7	22	143.9	199.5	206.9	70.6	4.2	3.3	71.1	82.6
26	2010	91.8	61.9	104.6	27.2	93.6	161.4	155.4	15.8	4.2	7.3	75.3	6.6
27	2011	16.6	1.5	174.5	165.3	164.6	140.1	126.1	47.7	28.1	9.4	0	0
28	2012	0	100.6	90.1	32.5	138.4	161.8	178.2	66.5	33.8	2.8	17.8	4.5
29	2013	4.5	-99	76.4	48.2	106.6	214.3	151.5	55.1	37.4	0.4	19.1	36.1
30	2014	77.8	34.2	23.3	74.1	108.1	212	-99	-99	-99	-99	-99	-99
31	2015	1.5	56.9	53.6	-99	-99	164	-99	-99	-99	-99	-99	-99

OGOLCHO													
No	Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1985	9.2	3	-99	63.1	45.5	34.5	159.5	-99	72.9	1.5	0	0
2	1986	0	73.8	219.2	31.2	110.3	-99	-99	73.2	87.3	-99	-99	-99
3	1987	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
4	1988	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
5	1989	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
6	1990	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
7	1991	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
8	1992	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
9	1993	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
10	1994	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
11	1995	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
12	1996	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
13	1997	-99	0	147.6	104.3	29.6	62.5	166.4	56.4	97	59.3	4.3	0
14	1998	18.3	22.4	78.6	58.4	86.2	66.6	138.2	147.4	134.3	65.9	8.2	0
15	1999	-99	-99	18.4	3.5	39.8	103.7	81.8	94.9	86.4	167	0	0
16	2000	0	0	0	49.9	75	69.5	160.8	100.3	129.7	20.9	113.6	0
17	2001	0	4	123.4	10.7	100.3	131.8	115.9	177.3	23.9	12.3	0	4.1
18	2002	0.8	41.5	26.1	44.2	34.8	69.5	133.9	183.4	39.3	2	0	7.8
19	2003	6.1	58.1	90.8	86.5	33.4	-99	-99	-99	-99	-99	-99	-99
20	2004	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
21	2005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
22	2006	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
23	2007	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
24	2008	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
25	2009	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
26	2010	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
27	2011	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
28	2012	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
29	2013	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
30	2014	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
31	2015	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99

SAGURE													
No	Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1985	-99	0	-99	-99	66.9	43.3	112.4	-99	33	51.3	7.1	5.3
2	1986	0.2	56.5	54	120.1	96.1	110.4	127.6	151.6	31.7	24.3	-99	-99
3	1987	-99	-99	-99	108.3	120.8	55.4	92	87.5	61.8	28.1	0.7	0
4	1988	7.3	31.3	7	139.9	57.1	72	235.5	178.4	133.2	35.1	1.4	0
5	1989	0.6	19.6	51	79.9	6.3	94.1	104.7	107.7	96.1	21.1	16.3	18.7
6	1990	4.9	133	127.7	63.1	53.1	83.4	125.6	97.3	96.2	9.2	19.1	1.4
7	1991	3.4	26.2	104.2	16.1	29.7	76	155.2	168.7	117.1	6.5	0.4	5.5
8	1992	24.1	81.8	61.8	67.5	36.9	76.5	115.1	222.6	58.1	57.8	13.1	12.6
9	1993	10	34.6	21.7	170.4	127.1	60.9	115.3	152.1	77.1	67.5	0	0.2
10	1994	0	9.9	33.2	53.9	24.1	149.8	174.3	138.2	103.7	1.1	11.3	2.1
11	1995	0	16.9	37.8	130.4	32.2	56.4	247.1	165.4	67	9.8	0	18.3
12	1996	28.1	9.2	78.8	10	127.9	159.9	105.2	100.6	58.8	4	3.7	1.6
13	1997	31.7	0	39.7	104.1	47.5	59	166.6	108.9	67.2	49.8	18.2	0
14	1998	24.1	37	61.7	75.6	62	58.4	125.3	181.2	29.7	91.9	9.6	0
15	1999	6.5	2.2	17.7	31	-99	-99	-99	-99	-99	-99	-99	-99
16	2000	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
17	2001	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
18	2002	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
19	2003	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
20	2004	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
21	2005	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
22	2006	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
23	2007	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
24	2008	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
25	2009	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
26	2010	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
27	2011	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
28	2012	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
29	2013	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
30	2014	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99
31	2015	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99	-99

Appendix II

Summarized Table of T- Test (Test for Absence of Trend) for katar								
No	station	Sample size N	T -Test				$t\{V, 2.5\%\} < t_t < t\{V, 97.5\%\}$	Result
			v	sumation of $\sum_{n=i}^{n}(D_i)^2$	R_{sp}	t_t		
1	Arata	10	8	64	0.612121	2.2	$-2.31 < t_t < 2.31$	PASS
2	Bekoji	10	8	164	0.006	0.017	$-2.31 < t_t < 2.31$	PASS
3	Ketera genet	10	8	234	0.4181	-1.3	$-2.31 < t_t < 2.31$	PASS
4	Kulumsa	10	8	164	0.006	0.017	$-2.31 < t_t < 2.31$	PASS
5	meraro	10	8	278	-0.688	-2.2	$-2.31 < t_t < 2.31$	PASS
6	sagure	10	8	156	0.0545	0.15	$-2.31 < t_t < 2.31$	PASS

Where $\mathrm{t_t} = \mathrm{R_{sp}}\left(\frac{\mathrm{n}-2}{1-\mathrm{R_{sp}}^2}\right)^{1/2}$

$$\mathrm{R_{sp}} = 1 - \frac{6 * \sum_{\mathrm{n=i}}^{\mathrm{n}}(\mathrm{D_i})^2}{\mathrm{n} * [(\mathrm{n} * \mathrm{n}) - 1]}$$

$$D_i = Kx_i - Ky_i$$

$$V = n - 2$$

Tests for Stability of Variance and Mean						
Parameters	Arata	Bekoji	Ketera genet	Kulumsa	meraro	sagure
n	5	5	5	5	5	5
x-	667.36	1060.5	817.02	869.3	903.62	727.66
s	1304.858011	2058.431	1594.375103	1692.137	1797.865	1432.016
s12	1702654.428	4237137	2542031.97	2863328	3232317	2050669
n	5	5	5	5	5	5
x-	783.78	1097.16	710.2	842.2	626.58	767.1
s	1575.570186	2129.05	1376.481605	1638.247	1289.664	1491.523
s22	2482421.41	4532854	1894701.61	2683854	1663233	2224640
v1	4	4	4	4	4	4
v2	4	4	4	4	4	4
V	8	8	8	8	8	8
ft	1	1	1.3	1.1	1.9	1
tt	-0.12725092	-0.02768	0.113398132	0.025729	0.27998	-0.04265
Result	PASS	PASS	PASS	PASS	PASS	PASS

Appendix III

Mean Monthly Stream Flow data of Katar river at Abura gauging station

	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
1988	1.85	2.12	2.02	2.30	2.52	2.73	22.99	99.43	34.52	20.32	5.17	2.69
1989	2.40	2.35	2.33	6.39	5.80	3.93	12.84	25.06	29.16	12.10	3.43	4.01
1990	2.81	10.95	20.02	21.31	5.30	4.31	13.44	35.42	32.61	9.12	2.99	2.39
1991	2.16	2.24	3.76	5.39	2.77	3.44	14.05	45.78	36.07	6.14	2.56	2.31
1992	2.02	2.46	1.76	3.04	3.07	3.23	8.18	65.98	53.99	25.08	4.56	2.83
1993	2.71	6.55	2.19	5.10	11.51	11.56	16.41	52.83	35.71	20.12	7.17	2.70
1994	2.14	1.92	1.64	1.56	2.49	4.27	22.93	68.87	49.09	7.02	2.81	2.04
1995	1.56	1.58	7.94	7.23	5.44	2.54	12.60	48.41	59.32	4.59	2.35	2.11
1996	2.48	1.69	2.86	3.93	6.74	17.94	21.50	64.12	24.38	8.54	2.44	2.16
1997	2.91	1.67	1.57	6.00	2.60	2.74	13.57	20.98	11.05	5.58	6.96	2.94
1998	2.19	3.45	5.01	2.38	5.99	3.66	13.40	69.19	49.60	28.12	6.76	2.36
1999	1.99	0.43	1.71	1.65	1.69	3.19	17.00	33.86	21.21	44.47	7.45	2.34
2000	1.58	1.58	1.56	1.49	4.67	2.75	9.73	49.31	28.69	13.50	4.30	2.51
2001	1.76	1.55	2.17	2.57	7.57	13.82	34.32	80.06	37.86	10.45	2.45	1.79
2002	1.84	1.90	2.77	2.08	2.80	3.43	7.29	26.57	13.45	3.33	1.48	1.92
2003	2.44	1.39	1.55	3.93	3.80	2.44	16.62	51.94	28.99	7.50	1.84	1.85
2004	1.47	1.34	1.35	8.71	3.52	3.32	20.04	38.03	26.83	13.57	2.22	1.41
2005	1.51	1.39	2.29	2.74	13.87	4.01	29.12	58.96	34.10	10.95	2.62	1.60
2006	1.34	1.64	2.15	11.56	7.50	4.70	38.20	79.89	41.37	8.34	3.01	1.79
2007	1.16	1.89	1.01	3.62	3.85	11.76	28.83	67.17	58.43	12.16	2.26	1.09
2008	1.05	1.58	0.89	2.70	2.46	5.78	38.20	73.53	49.90	8.34	3.01	1.79
2009	1.57	1.27	0.77	1.78	1.06	1.25	7.64	24.92	27.57	6.49	2.26	1.09
2010	1.57	3.50	9.22	14.39	39.14	9.66	44.47	65.40	46.69	9.04	1.64	1.11
2011	0.96	0.76	1.01	0.77	3.76	5.85	14.50	39.88	38.32	6.16	1.82	0.96
2012	0.47	0.62	0.62	3.05	2.65	1.62	12.57	31.98	39.39	8.06	1.72	0.68

Appendix IV

SNAM	LAYERS	HYDGRP	SOLZMX	ANIONEXCL	SOLCRK	TEXTURE	SOLZ1	SOLBD1	SOLAWC1	SOLK1	SOLCBN1	CLAY1	SILT1	SAND1	ROCK1	SOLALB1	USLEK1	SOLEC1
Pellic vertisols	2	D	1200	0.5	0.5	SaC-CL	800	1.53	0.11	2.41	0.67	35.25	16.2	48.7	0	0.01	0.3	0
Orthic luvisols	3	B	2000	0.5	0.5	Lsa-SaCL-C	800	1.45	0.05	48.5	0.25	11.5	4.2	84.35	0	0.01	0.2	0
Eutric nitisols	3	B	2000	0.5	0.5	SaL-SaCL-SiCL	800	1.5	0.06	26.6	0.28	16.7	6.05	77.25	0	0.01	0.16	0
Chromic luvisols	7	B	1800	0.5	0.5	SiL-SiL-SiL-SiL-SiL-SiL-SiL	210	1.45	0.22	38.4	1.2	11	67	22	0	0.13	0.3	0
Eutric cambisols	2	B	900	0.5	0.5	L-L	600	1.5	0.2	33.6	1.63	21	33	46	0	0.01	0.31	0
Vitric andosols	3	B	2000	0.5	0.5	SL-SL	800	1.53	0.09	48.2	1.4	9.3	26.4	64.5	0	0.01	0.49	0
Vertic cambisol	3	D	2000	0.5	0.5	C-C	800	1.33	0.13	0.83	1.1	50.7	26	23.3	0	0.01	0.49	0
Eutric Fluvisols	5	B	1700	0.5	0.5	LS	200	1.1	0.11	25	2	50	34	17	5	0.13	0.22	0
mollic andosols	3	B	2000	0.5	0.5	SL-SL	800	1.53	0.09	38.2	1.4	9.3	28.4	62.5	0	0.01	0.49	0

SNAM	LAYERS	HYDGRP	SOLZMX	ANIONEXCL	SOLCRK	TEXTURE	SOLZ2	SOLBD2	SOLAWC2	SOLK2	SOLCBN2	CLAY2	SILT2	SAND2	ROCK2	SOLALB2	USLE K2	SOL EC2
Pellic vertisols	2	D	1200	0.5	0.5	SaC-CL	1200	1.15	0.15	2.41	0.6	65.5	11.2	23.4	0	0.01	0.3	0
Orthic luvisols	3	B	2000	0.5	0.5	Lsa-SaCL-C	1200	1.5	0.11	6.72	0.43	25.7	22.7	51.65	0	0.01	0.3	0
Eutric nitisols	3	B	2000	0.5	0.5	SaL-SaCL-SiCL	1200	1.15	0.11	4.06	0.68	31.1	16.85	52	0	0.01	0.16	0
Chromic luvisols	7	B	1800	0.5	0.5	SiL-SiL-SiL-SiL-SiL-SiL-SiL	260	1.46	0.21	37.2	0.3	14	66	20	0	0.13	0.3	0
Eutric cambisols	2	B	900	0.5	0.5	L-L	900	1.46	0.18	39.68	1.1	13	46	41	0	0.01	0.34	0
Vitric andosols	3	B	2000	0.5	0.5	SL-SL	1200	1.12	0.09	56.19	0.84	6.7	26.3	67	0	0.01	0.49	0
Vertic cambisol	3	D	2000	0.5	0.5	C-C	1200	1.33	0.12	0.79	0.53	53.9	26.1	20	0	0.01	0.49	0
Eutric Fluvisols	5	B	1700	0.5	0.5	LS	500	1.04	0.11	25	2.3	50.9	22	27.1	0	0.13	0.2	0
mollic andosols	3	B	2000	0.5	0.5	SL-SL	1200	1.12	0.09	56.19	0.84	6.7	26.3	67	0	0.01	0.49	0

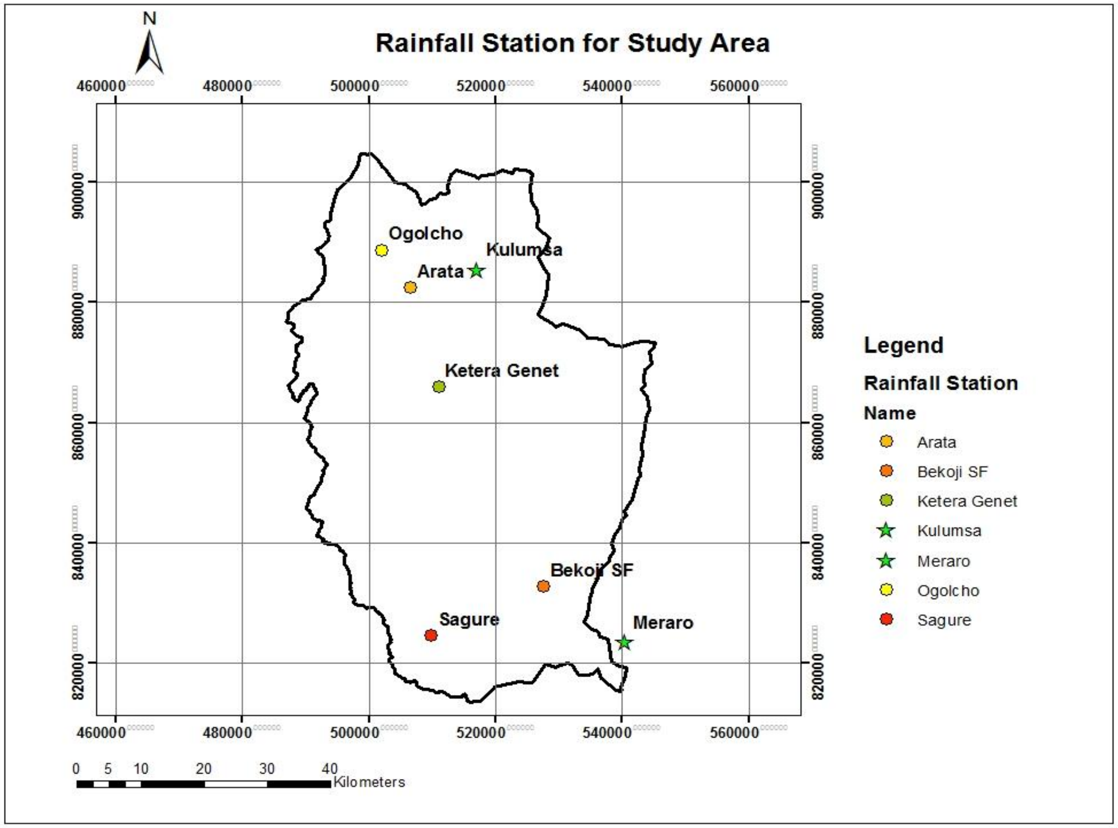
SNAM	LAYERS	HYDGRP	SOLZMX	ANIONEXCL	SOLCRK	TEXTURE	SOLZ3	SOLBD3	SOLAWC3	SOLK3	SOLCBN3	CLAY3	SILT3	SAND3	ROCK3	SOLALB3	USLEK3	SOLEC3
Pellic vertisols	2	D	1200	0.5	0.5	SaC-CL	0	0	0	0	0	0	0	0	0	0	0	0
Orthic luvisols	3	B	2000	0.5	0.5	Lsa-SaCL-C	2000	1.47	0.12	0.63	0.53	43.9	12.85	43.3	0	0.01	0.3	0
Eutric nitisols	3	B	2000	0.5	0.5	SaL-SaCL-SiCL	2000	1.1	0.16	3.41	0.91	63.3	18.55	17.95	0	0.01	0.08	0
Chromic luvisols	7	B	1800	0.5	0.5	SiL-SiL-SiL-SiL-SiL-SiL-SiL	460	1.45	0.2	34.8	0.21	19	59	22	0	0.13	0.3	0
Eutric cambisols	2	B	900	0.5	0.5	L-L	0	0	0	0	0	0	0	0	0	0	0	0
Vitric andosols	3	B	2000	0.5	0.5	SL-SL	2000	1.38	0.13	0.12	0.65	75	17.58	7.42	0	0.07	0.49	0
Vertic cambisol	3	D	2000	0.5	0.5	C-C	2000	1.38	0.13	0.12	0.65	75	17.58	7.42	0	0.07	0.49	0
Eutric Fluvisols	5	B	1700	0.5	0.5	LS	900	1.03	0.12	25	2.5	38.9	40	21.1	0	0.13	0.2	0
mollic andosols	3	B	2000	0.5	0.5	SL-SL	2000	1.38	0.13	0.12	0.65	75	17.58	7.42	0	0.07	0.49	0

SNAM	LAYER NUMBER	HYD GRP	SOL ZMX	ANIONEX CL	SOLCRK	TEXTURE	SOL Z	SOL BD	SOL AWC	SOL K	SOL CBN	CLAY	SILT	SAND	ROCK	SOL ALB	USLE K	SOL EC
Chromic luvisols	4	B	1800	0.5	0.5	SiL	650	1.5	0.2	33.6	0.2	22	56	22	0	0.13	0.3	0
	5	B	1800	0.5	0.5	SiL	950	1.5	0.2	36	0.2	17	57	26	0	0.13	0.3	0
	6	B	1800	0.5	0.5	SiL	1350	1.5	0.2	36	0.1	17	57	26	0	0.13	0.3	0
	7	B	1800	0.5	0.5	SiL	1800	1.5	0.21	36	0.1	16	59	25	0	0.13	0.3	0
Eutric Fluvisols	4	B	1700	0.5	0.5	LS	1300	1	0.2	25	1.7	36.9	34	29.1	0	0.13	0.2	0
	5	B	1700	0.5	0.5	LS	1700	1	0.1	60	0.4	58.9	30	11.1	0	0.13	0.2	0

Appendix V

Parameters	Value
Precipitation	840.0mm
Snow fall	0.00 mm
Snow melt	0.00mm
Surface Runoff Discharge	3.51mm
Lateral soil Discharge	92.71mm
Groundwater (shal. Aq.)	75.07mm
Deep aq. recharge	2.34mm
Total aq recharge	133.73 mm
Total water Yield	173.62mm
Percolation out of soil	133.82 mm
Actual evapotranspiration (ET)	608.9mm
Potential evapotranspiration (PET)	1418.6mm
Total Sediment Loading	2.1 t/ha

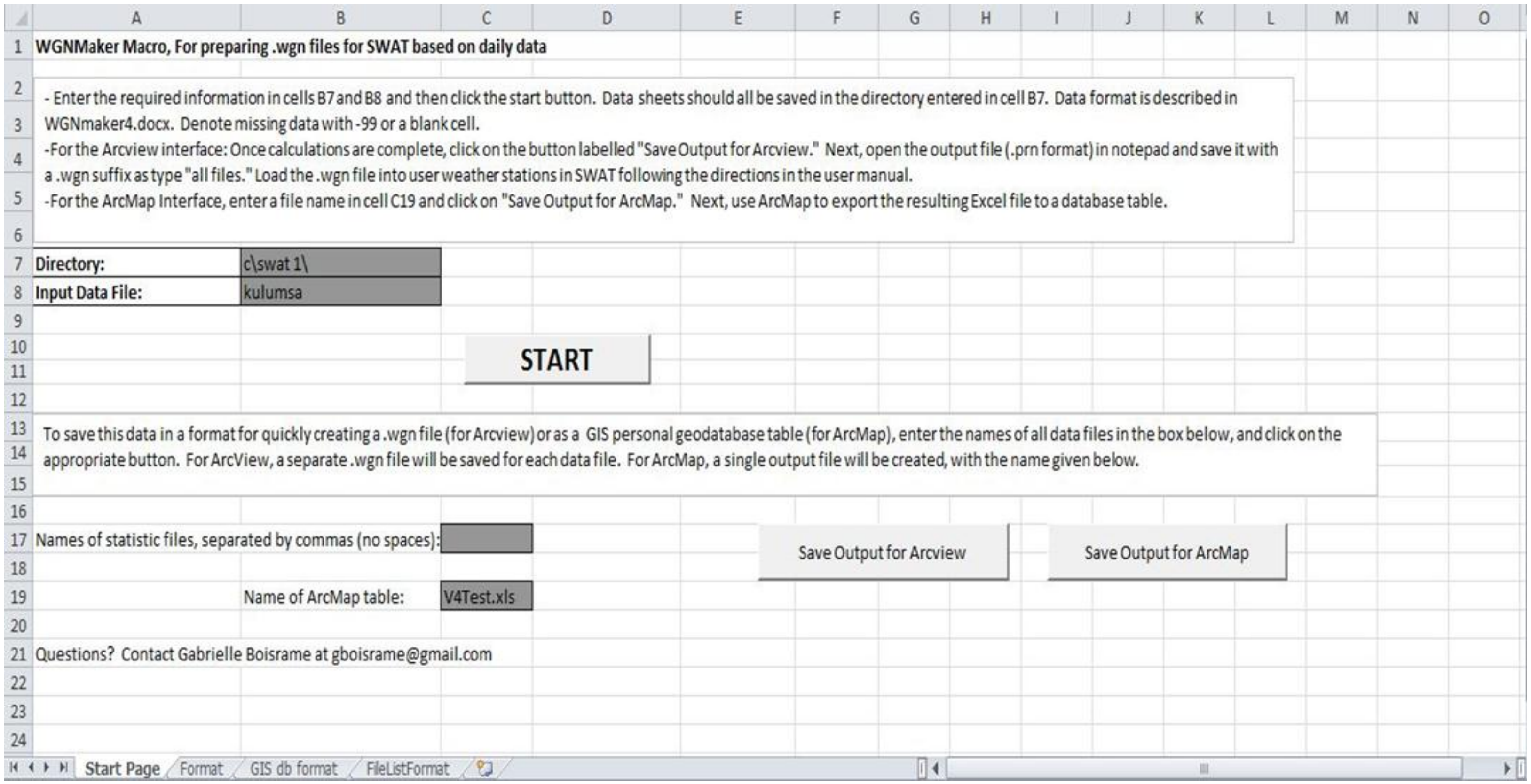
Appendix VI



N
Rainfall Station for Study Area
460000
480000
500000
520000
540000
560000
900000
880000
860000
840000
820000
Ogolcho
Kulumsa
Arata
Ketera Genet
Bekoji SF
Sagure
Meraro
0 5 10 20 30 40
Kilometers
Legend
Rainfall Station
Name
Arata
Bekoji SF
Ketera Genet
Kulumsa
Meraro
Ogolcho
Sagure

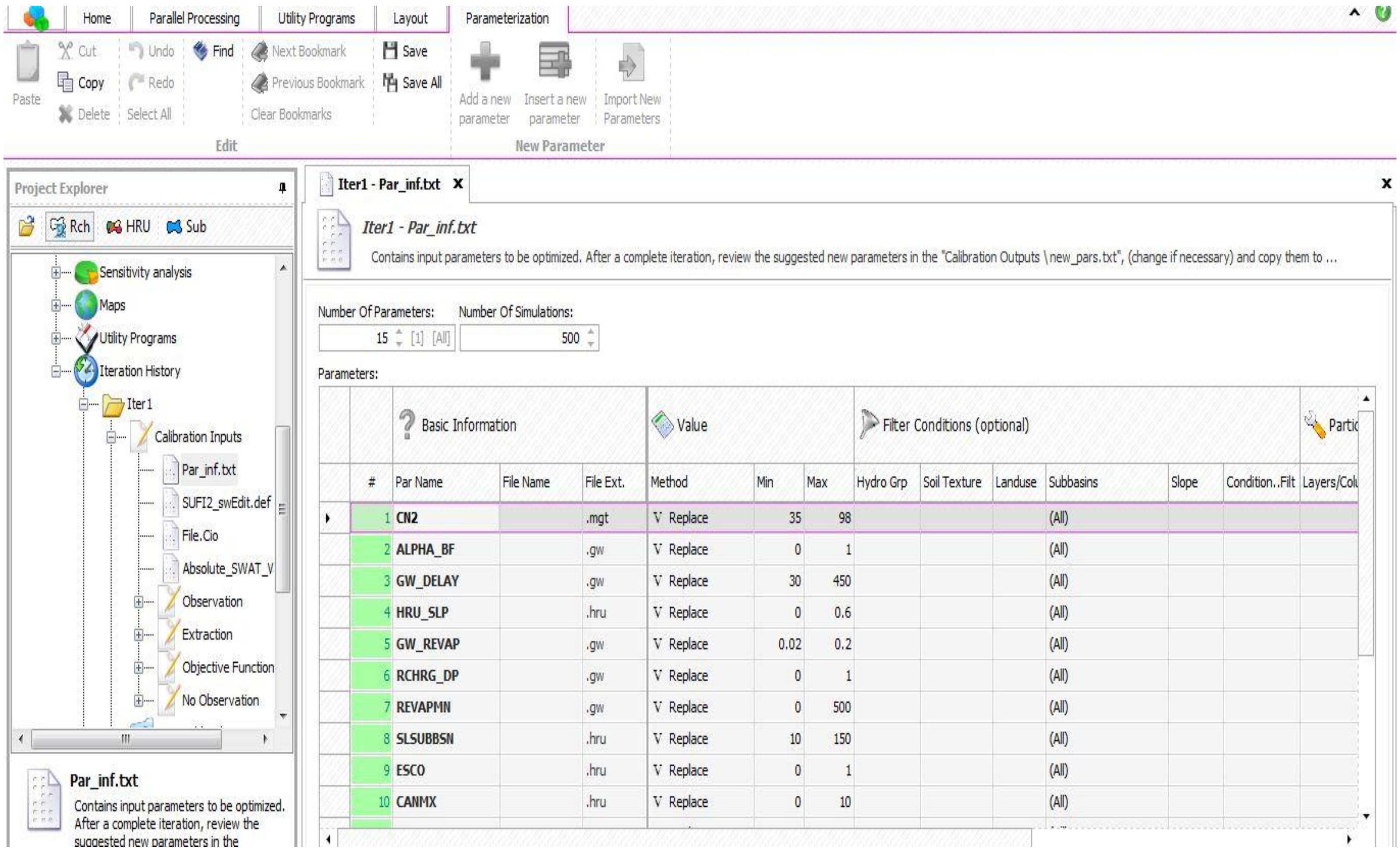
Appendix VII

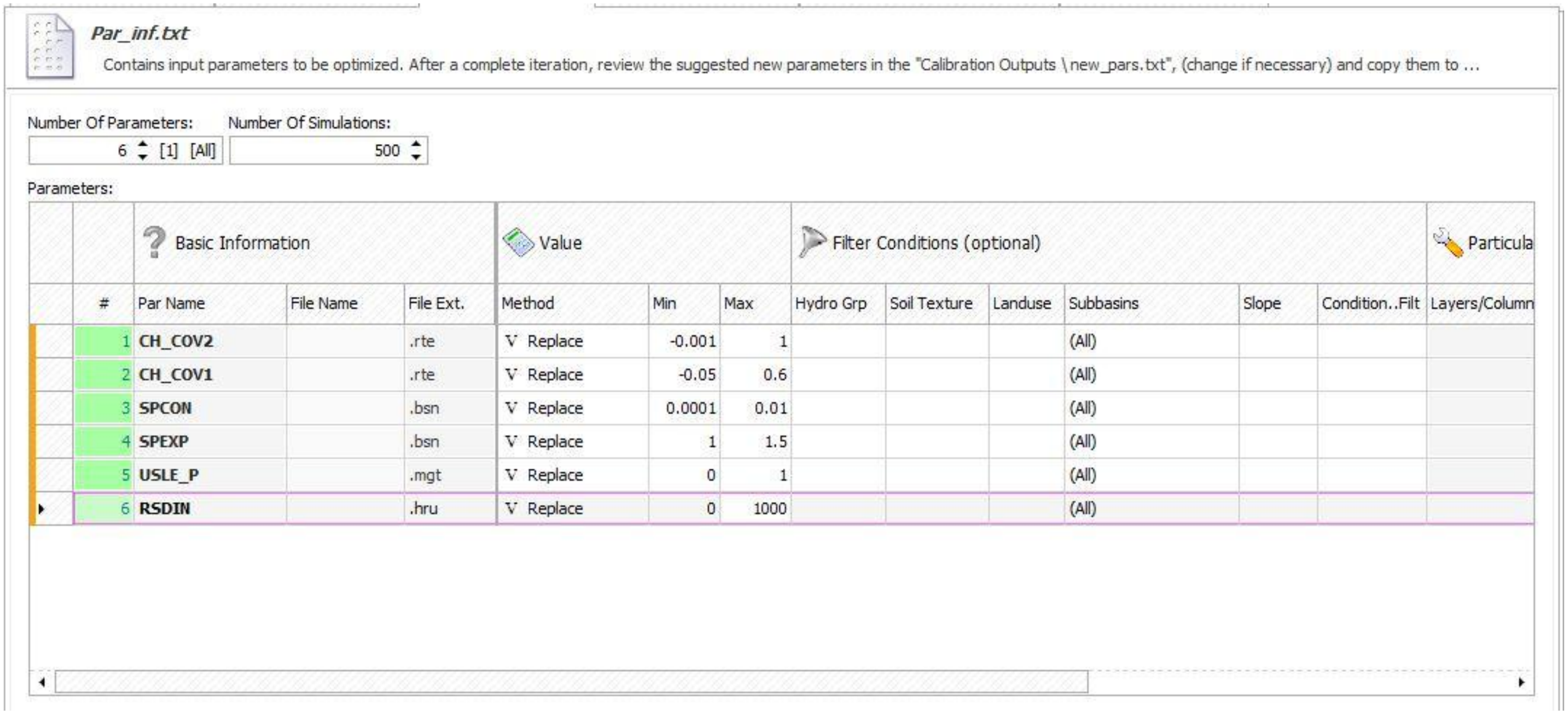
Screen Shot of WGN Maker 4.1 Program



Appendix VIII

Screen Shot of SWAT CUP Program





Par_inf.txt

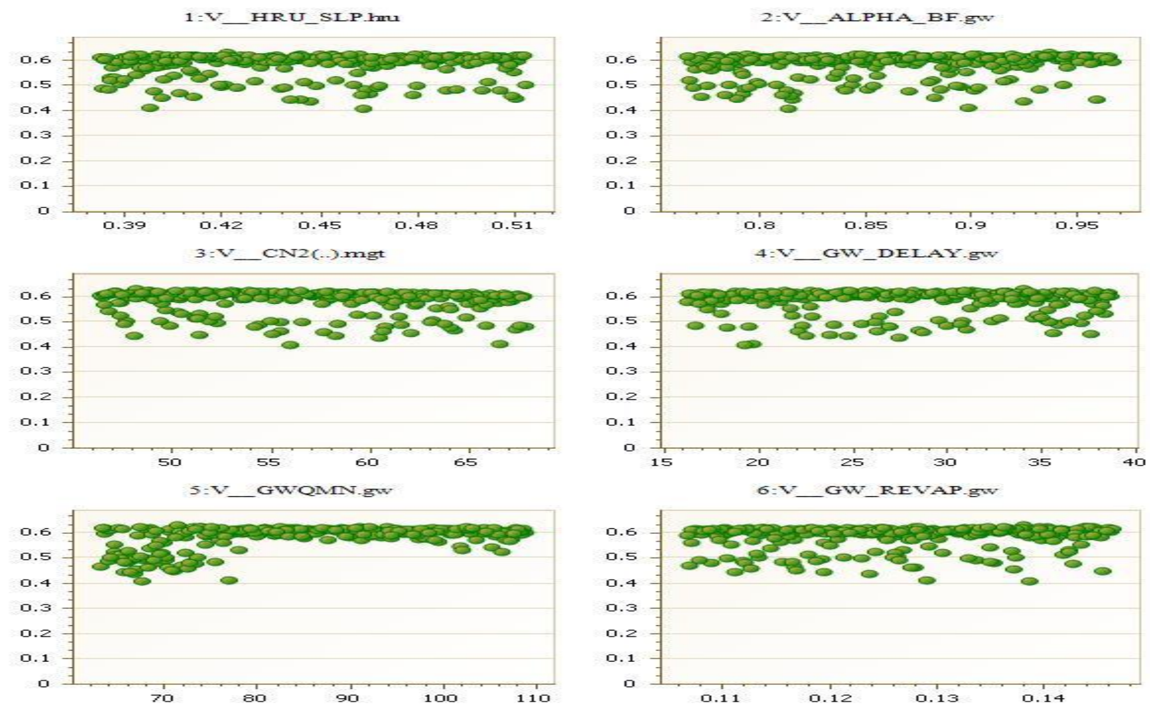
Contains input parameters to be optimized. After a complete iteration, review the suggested new parameters in the "Calibration Outputs \ new_pars.txt", (change if necessary) and copy them to ...

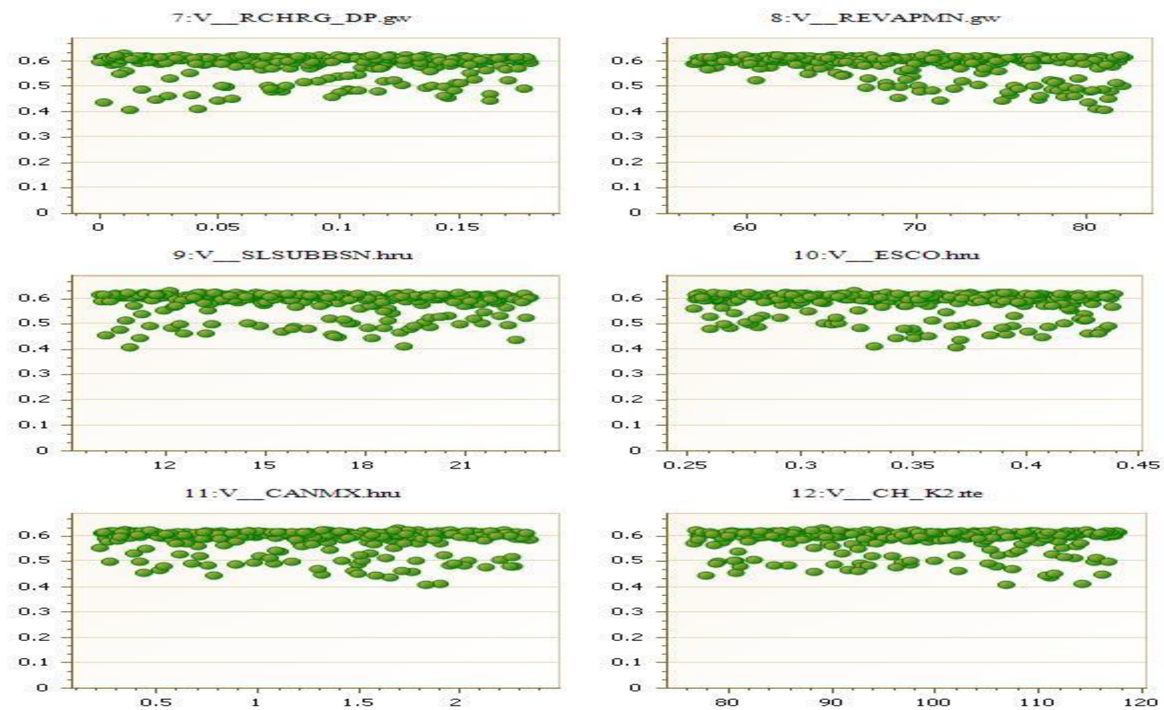
Number Of Parameters: 6 [1] [All]   Number Of Simulations: 500

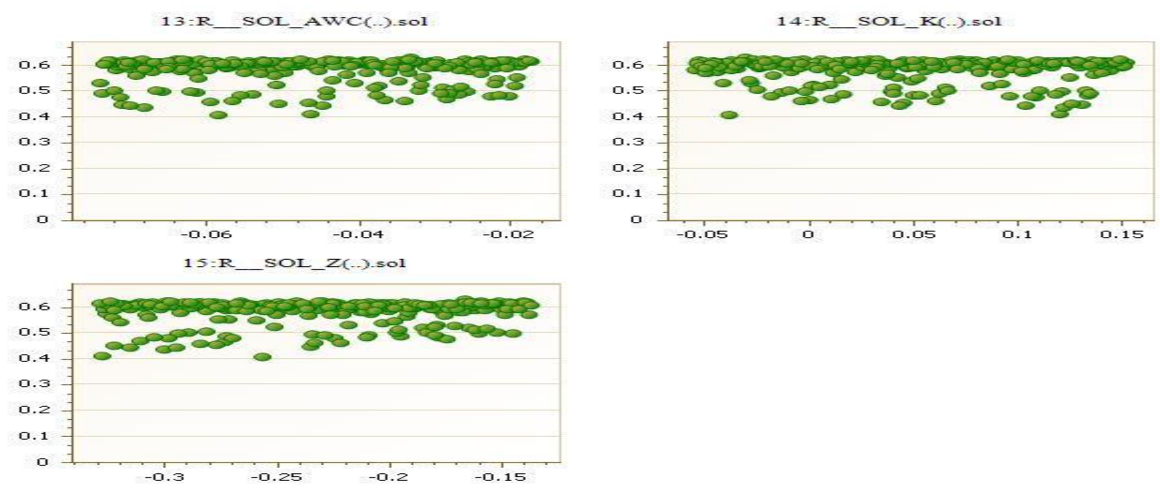
Parameters:

	Basic Information			Value			Filter Conditions (optional)						Particula
#	Par Name	File Name	File Ext.	Method	Min	Max	Hydro Grp	Soil Texture	Landuse	Subbasins	Slope	Condition..Filt	Layers/Column
1	CH_COV2		.rte	V Replace	-0.001	1				(All)			
2	CH_COV1		.rte	V Replace	-0.05	0.6				(All)			
3	SPCON		.bsn	V Replace	0.0001	0.01				(All)			
4	SPEXP		.bsn	V Replace	1	1.5				(All)			
5	USLE_P		.mgt	V Replace	0	1				(All)			
6	RSDIN		.hru	V Replace	0	1000				(All)			

Dotty plots for stream flow


1:V__HRU_SLP.hru
2:V__ALPHA_BF.gw
3:V__CN2(..).mgt
4:V__GW_DELAY.gw
5:V__GWQMN.gw
6:V__GW_REVAP.gw


7:V__RCHRG_DP.gw
8:V__REVAPMN.gw
9:V__SLSUBBSN.hru
10:V__ESCO.hru
11:V__CANMX.hru
12:V__CH_K2.rte


13:R__SOL_AWC(..).sol
14:R__SOL_K(..).sol
15:R__SOL_Z(..).sol
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.06
-0.04
-0.02
-0.05
0
0.05
0.1
0.15
-0.3
-0.25
-0.2
-0.15

Dotty plots for sediment yield